RESEARCH AND DATA NEEDS FOR EVALUATION OF SOIL AND MOISTURE MANAGEMENT ALTERNATIVES IN WEST AFRICA

by

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Authorities assert that the overriding challenge to agriculture in the West African semi-arid tropics (WASAT) is feeding the region's ever increasing population (Norman). This assertion is based on the observation that moderate growth in the production of staple foods has not kept pace with population increases in the area. For example, per capita food production in the region declined by 2 percent per annum from 1976 through 1980 and estimated per acre yields for sorghum and millet, the two staple grain crops, have declined in recent years (Paulino). Lengthy dry spells in the WASAT, such as the 1968 to 1972 drought, are compounding the problems of food production. Finally, authorities cite the drastic increase in food imports and increases in incidences of malnutrition and even starvation as evidence of a falling agriculture.

The international reaction to the food crisis in the WASAT has historically taken two forms: 1) massive shipments of food grains have periodically flowed into the region; and 2) donor agencies have intensified their search for information on the best means of aiding the region's drought recovery and long-term development (Eicher and Baker). The AID's Technology for Soil and Moisture Management (TSMM) project is an example of the perception that long-term development of the area's agriculture is in order and that outside aid is necessary for that development.

An emphasis on long-term development is seen as being essential because low resource productivity in the region is causing actual levels of aggregate food production to fall far short of their maximum potential (TSMM Project Report). Possibly just as important, present agricultural practices result in significant amounts of resource degradation, often in the form of soil erosion on cropland. Accordingly, even present productivity cannot be sustained unless steps are taken to better protect the land. Any long-term solution to the problem of inadequate levels of food production must not only raise resource productivity but also increase the conservation of natural resources. One must interject the observation that conservation of resources for the long run may require short run decreases in the growth rate of current food production.

Economics and the Research Process

One can argue that national governments in the WASAT seek to introduce productivity-enhancing and resource-conserving technologies to the farming community in the region as an overriding agricultural policy goal. In light of this goal, researchers have the task of developing agricultural production techniques that will increase current and future levels of food production in the region. An equally important job is insuring farmer use of these new production methods. The primary role of economists involves the latter task as it centers on examining the conditions under which technologies will be adopted.

Economic models should be based on the fact that there are necessary conditions for a successful and equitable agricultural policy at the individual farm level, at the resource or ecological region level, at the agricultural market level, and at the overall social level.

At the individual farm level, economists seek to predict how farmers will react to the introduction of new technologies or new policies and ascertain the possible reasons why farmers may or may not accept new practices. Farm-level models should also help predict the ultimate effect of new technologies and policies on both the efficiency of food production and the wealth and utility position of households. Finally, models may be used to assess the effects of new technologies on natural and other resources at the farm level and ascertain how farmers account for such impacts in their decision making.

Policies must also be economically viable under long run market conditions--including market imperfections--and socially viable under existing policy constraints. Accordingly, research examining the physical and institutional infrastructure and the economics of input and output markets may be required. Institutional research sheds light on the legal and social setting and the interaction of that setting with various economic factors. Hence, such research can demonstrate how the legal-social framework either facilitates or hinders policy implementation.

Combining predictive economic models of the farm, market, and overall social setting should be the ultimate research goal. These paradigms can then be used in conjunction--and in a normative fashion--to gauge the economic efficiency and distributional implications, and political and social feasibility, of alternative policies. Economists can then provide analytical support for policy makers by 1) indicating the necessary conditions for policies that seek to increase farmer use of new technologies; 2) showing the advantages and disadvantages of such policies; and 3) demonstrating what tools (e.g., changes in property rights) are needed for implementing the policies.

The most basic element in studying technology adoption in agriculture is modeling farm level decisions and the effects of these decisions. Therefore, researchers must decide on which subareas of economics to use in formulating their models of farm family behavior. The essential nature of the agricultural production problem in WASAT, i.e., low resource productivity and resource degradation, implies the use of both the farm management and resource economics approaches to economic modeling of the food production problem.

The farm management approach serves to focus our attention on the decisions of the farm family concerning the adoption of productivity-increasing technologies. It helps emphasize the constraints under which farm decisions are made and the tradeoffs which farmers must make in deciding whether to use new technologies. Models of farm management decisions also incorporate the biological and agronomic conditions under which choices are made.

Resource economic models are well adapted for examining the problem of resource degradation in general and farmland soil erosion in particular. Natural resource economists often view natural resource degradation in light of the costs that current users of the resource impose on future resource users. In studies of cropland degradation through soil erosion, "the economic nature of the (degradation) problem can be characterized as a trade-off between current production and the future productivity of the soil resource" (p.1, Krautkraemer).

Modeling Needs and Approaches to Resource Degradation

The emphasis on land degradation in the WASAT centers on the processes of soil erosion on croplands. Soil erosion results in costs that are either on-site or off-site in character. On-site costs result from a decline in the productivity of the land which is being eroded (Crosson). Off-site costs occur whenever eroded soil is deposited in other locations thereby inhibiting the productive use or enjoyment of resources in these locations. A good example of off-site costs is a decline in water quality caused by siltation.

From a farm level focus, off-site effects are ignored under two caveats: 1) in terms of total social accounts off-site effects could be very important; 2) a farm family could find off-site effects from a neighboring farm to be very important if the neighbor's production decisions alters their farm's resource endowment. For example, increased rates of soil erosion on a farm could be caused by an increase in rainfall runoff from a farm upslope. Under our assumption, the upslope farmer would not concern himself with the degradation that he has caused on the downslope farm.

Modeling Farm On-Site Effects

As previously mentioned, the nature of soil erosion is such that future soil productivity is affected by current decisions about crop production. If economic models ignore future costs due to current erosion, then policy recommendations based upon such models could result in erosion rates that are higher than "optimal" rates of erosion. This intertemporal nature of soil erosion implies that models which optimize over several time periods are appropriate because such models incorporate the future costs of present production decisions.

Several different tacks can be taken in studying how farmers account for the effects of current erosion on future productivity. One approach is optimal control theory where an objective function is optimized over several future periods of time. A second method is a multistage optimization problem, which can be solved through the use of dynamic programming. A third approach also employs a multistage optimization problem, but it does not rely on the dynamic programming method for its solution. Each of the three approaches rely on the concept of user costs, which is the value of lost future production from a resource due to current use (depletion) of the resource. For example, topsoil eroded by current farm practices, and, therefore, not available for future use, can negatively influence future yields.

Empirical estimation of the relationship between erosion and crop productivity can be based on the multistage optimization model. As opposed to dynamic programming or optimal control models, in an empirical application of a simplified multistage optimization, the number of time periods (t) is reduced to two--the current year and all future years. Erosion in the current production period (t=1) is assumed to affect soil productivity in all the future years that constitute the t=2 period. Stated differently, we are looking at the user costs arising from production in only the current year, but the user cost is a summation of productivity losses that will occur over several years. User costs consist of lost production that arises in the remaining years in the planning horizon as a result of current erosion. For example, if we assume a planning horizon of 5-years then t=2-5 covers years 2 through 5 of that horizon.

Declines in crop yields as a function of erosion may be taken from equations based on research such as that carried out by Lal for maize and cowpeas (Lal; Stocking and Peake). In these equations, yield losses are stated as a function of soil erosion rather than remaining soil depth as is the case for many theoretical models of erosion over time, but the empirical equations still measure the user costs--i.e., lost productivity--from current erosion. Lal's yield loss equation for maize on a 5 percent slope is

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

and for cowpeas on a 5 percent slope

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

where Y is yields measured in metric tons and X is cumulative erosion measured in tons per hectare. As shown in Table 1, Lal's two equations can be solved to find yield loss per tons of soil loss. If data on erosion is missing for other crops, estimates could be obtained by relating the needed data to what is available. For example, declines in yields for maize, millet, and sorghum on semi-arid dry lands might be assumed to be some percentage of the decline in yields found on Lal's much higher yielding maize plots. Similarly, groundnut yield declines attributable to erosion might be assumed to be 50 percent of Lal's estimate of cowpeas yield loss from erosion.

Over a four year period--i.e., years 2-5 in the planning modeling--the loss in soil that occurs in year t-1 can be converted into a coefficient, which can be entered into the objective function of a mathematical programming model. Such a coefficient, as found in Table 2, is the summation over years 2 through 5 of the product of yield decline per ton of erosion, the expected constant price of the crop, and a discount factor. The coefficient is a measure of the expected loss in future income per unit of current erosion. As such it is not an actual current cost, but an anticipated future cost. Including the soil damage coefficient in the objective function of a mathematical programming model allows us to model uses of the soil resource where farm families account for the on-site opportunity costs of erosion, in terms of lost soil productivity, in their decisions.

The Dynamics of Soil Use Under a Bush Fallow System

The previous discussion of the relationship between farming and soil loss assumes continuous cropping. Much of the agriculture in the WASAT is characterized by the bush fallow farming method, however. In such a system, neither a process of permanently idling or permanently farming the land is optimal; rather, land use is a cycle of farming and fallowing over time.

Control theory or dynamic programming models are especially well suited for the study of bush fallow farming. In either approach, "control variables" are given certain values over time called time paths--e.g., soil erosion is a function of soil use over time. The control variables in turn help determine the time paths taken by state variables--i.e., soil productivity--through a set of differential or difference equations called the equations of motion. The

TABLE 1. Yield Declines in Maize and Cowpeas Due to Erosion

Erosion (Tons)	Maize Yields	Marginal Change Maize Yields	Cowpea Yields	Marginal Change Cowpea Yields
	(M.Tons)			
0	6.70		0.64	
10	6.50	0.20	0.60	.04
20	6.31	0.19	0.57	.03
30	6.12	0.19	0.53	.04
40	5.94	0.18	0.50	.03
50	5.77	0.17	0.47	.03
60	5.60	0.17	0.45	.02
70	5.43	0.17	0.42	.03
80	5.27	0.16	0.40	.02

SOURCE: Lal, Rattan. "Effects of Soil Erosion on Crop Productivity". The Critical Reviews in Plant Science, 5(4):303-367, 1987.
Stocking, Michael and Lewis Peake. "Crop Yield Losses from the Erosion of Alfisols". Tropical Agriculture Trinidad). 63(1):41-45, 1986.

TABLE 2. An Example of How to Measure the Expected Loss in Future Income Per Unit of Erosion

Year	Yield Per Unit Erosion (Kg/Ton)	Crop Output Price (Mf/Kg)	Discount Factor	Discounted Value Annual Yield Loss[1]	Total Damage (Coefficient)[2] (MF)
2	0.05	120.0	0.91	5.46	
3	0.05	120.0	0.83	4.98	
4	0.05	120.0	0.75	4.50	
5	0.05	120.0	0.68	4.08	
					19.02

[1]The discounted value annual yield loss equals yield loss per unit erosion multiplied by both the crop output price and the discount factor.

[2]The total damage coefficient in the mathematical programming model is the total value of the expected loss in productivity due to erosion. The total damage coefficient equals the sum of the discounted value of annual yield loss for years 2 - 5.

optimal time paths for the control variables result in the maximization of an objective function that depends on the time paths of the control and state variables (Intrilligator). As applied to bush fallow farming, either approach allows for predicting the optimal length of time for both cropping and fallowing-based on the changing condition of the new soil productivity state variable.

A very simple exposition of bush fallow farming over time, based on Krautkraemer's rigorous optimal control theory model of such a system, can be found in Figure 1. In Figure 1, curve A represents net benefits to farming at a particular time (t). Curve A is undulating over time because cultivation depletes soil productivity, thus causing the net return from farming to decline and eventually making the continuation of farming unprofitable. When exhausted land is fallowed, soil productivity is reconstituted. As a consequence, farming the land again will be desirable at some future time.

The curve denoted as R in Figure 1 represents the benefits from land in bush fallow that are not received if the land is farmed. Examples of such benefits include the provision of firewood and hunting. The points at which the net benefit curve A and the fallow benefit curve R intersect determines when the land switches between being farmed and being fallowed. Farming the land is optimal as long as net benefits from farming are greater than the opportunity costs of farming--i.e., $NB(t) > R(t)$ as over the range time C to time D in Figure 1. For the range where benefits fall below the opportunity costs of farming, (i.e., $NB(t) < R(t)$ for periods D to E) it is optimal to idle the land and allow the soil to regenerate until the net benefit function is again greater than the opportunity costs.

A key policy issue concerns the tradeoff between short run growth in food production and the long run maintenance of the soil resource base. In many

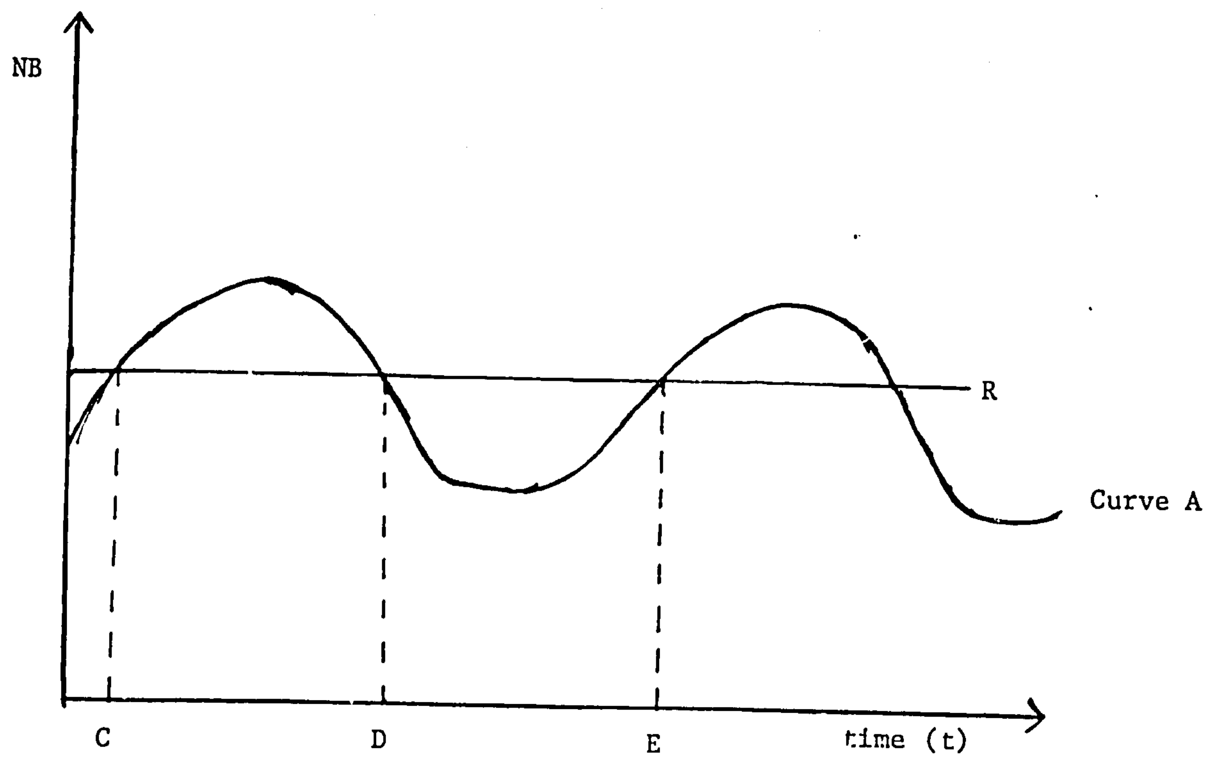

FIGURE 1. Net Benefits from Farming Versus Net Benefits from Fallowing in Bush Fallow Farming

areas, such as the Central Plateau in Burkina Faso, increased food production is primarily coming from the expansion in the amount of cultivated land as farmers move away from bush fallow to nearly continuous cultivation. A dynamic modeling approach would help indicate whether a bush fallow system is necessary or desirable for maintaining soil productivity and producing grazing and forestry products. If a bush fallow system is required, then what is the optimal cycle of soil use and soil regeneration in such a system?

Another policy question, which can be examined in a dynamic modeling context, concerns the benefits of policies other than fallowing that will maintain and, to some extent, regenerate the soil resource. Agroforestry can contribute to sustained soil productivity and also yield valuable firewood and animal feed. Will alternatives such as agroforestry practices lead to greater a net present value from the soil resource?

Recommendations for Research Relative to Land Degradation

Soil erosion has been discussed under the two alternative situations of continuous farming and bush fallow farming. We propose that different types of models should be used in studying these alternative farming methods.

The multiperiod optimization approach, where erosion damage values are endogenous in a linear programming framework, can continue to be applied to the continuous farming system. The present value of erosion damage could be included in any whole farm mathematical programming model. A possible extension would be including in the model measurements of rainfall runoff and off-site effects under various farm practices in addition to existing measurements of soil loss.

With regards to examining a system of bush fallow farming, new models of dynamic optimization need to be developed. Dynamic programming is a more tractable modeling approach than optimal control theory, and should be used, therefore, as a device for analyzing the economics of a bush fallow system.

Significant data needs exist for both the dynamic programming and multi-period optimization models. For example, researchers have been forced to use data on erosion rates and crop productivity loss due to erosion from research plots of the International Institute of Tropical Agriculture at Ibadan, Nigeria--an area not in the semi-arid tropics. Empirical measurements of changes in soil loss under various farm practices have also been difficult to locate.

Other data needs primarily relate to the dynamic programming model of bush fallow farming. Empirical data on the rate of soil regeneration for fallowed land is needed. Also required is information on the ability of farmers to substitute for the soil regenerating benefits of fallowing through the use of chemical and organic fertilizers, tied ridges, and other practices. In this regard, it may be possible to incorporate other research results into the dynamic program of a bush fallow system. Finally, research is needed on the benefits of fallowing other than soil building, such as animal grazing of fallow land.

Another approach is to use a dynamic optimal model of the bush fallow cycle to estimate the present value of a ton or milimeter of soil in the current year---that value can then be entered as the user cost in the single (current) period model.

Modeling Needs for and Approaches to Low Resource Productivity

Low factor productivity in agriculture, which results from both the poor quality of resources as well as constraints on the levels of resource use, is a major cause of inadequate aggregate food production in the WASAT. If increasing food production in the region is accepted as a policy goal, then both the inherent productivity (quality) of resources committed to agriculture must be increased and agricultural resources that are currently in short supply must be either augmented or replaced by appropriate substitutes.

A conceptual view of resource allocation at the family farm level will aid in the construction of empirical models which can be used to assess the needs for and limits to the use of untried farming methods as compared to traditional practices. Comparisons of the different components of a conceptual model and their empirical counterparts are shown in Table 3.

Basic to the conceptual model are biological crop production functions that comprise a multidimensional production possibilities set where farmers can use limited amounts of resources in the production of differing combinations of outputs. As a general rule, increased production of one good requires decreases in the level of other output(s) because resources are taken away from the latter and applied to the former.

Mathematical programming models provide an empirical method for estimating the multidimensional production possibilities set because such model provide a means of evaluating the tradeoffs in resource use between different output and input combinations. Programming models may be especially useful for evaluating new farming methods in West Africa because limits on resource endowments are often a major constraint to the use of new technologies by farmers in the area. For example, limited labor and capital may preclude intensive practices such as tied ridges because farmers cannot afford to own draft animals and equipment for labor-saving alternatives to hand construction of tied ridges.

Another basic component of the conceptual model is the assumption that the overriding goal of farm decisions is to maximize the utility of the farm family. Utility is either obtained by producing "nonagricultural" goods such as leisure

TABLE 3. Comparison of Conceptual and Empirical Models of Farm Family Decision Making.

Conceptual Model	Empirical Model
Biological Production Function	Mathematical Programming
Constrainted Optimization	Programming Model Constraints Relating to: Labor Land Capital
Multi-Goals	Increasing Net Returns Meeting Family Food Needs
Risk, Uncertainty, and the Dynamics of Decision Making	Various Empirical Approaches to Measuring Risk and Accounting for Decision Making Dynamics

of the farm family or by producing agricultural goods which are either directly consumed by the farm family or which lead to profits that enable the purchase of goods that provide utility. Given a fixed level of resources, tradeoffs must be made between the "production" of agricultural and nonagricultural goods such that the utility of the farm family is maximized (Heady). Accordingly, farmers may have other goals beside maximizing profits, such as providing an adequate diet, in years when crop yields are low.

A final part of the conceptual model is the commitment of resources over time. Adopting a technology generally involves the use of or changes in resources over more than one growing season. Using animal traction with oxen (ATO) requires long term investments in oxen and equipment. Technologies with less apparent long run effects--e.g., using chemical fertilizers--can cause changes in the quantity or quality of resources--e.g., aluminum buildup in the soil--over the long run. Therefore, technologies should be evaluated from both long and short run perspectives.

Specific Modeling Needs Recommendations

Once the framework for the conceptual and empirical model is established, one should decide which technologies, resource limits, and farm goals are key to the farm decision making process. Important technologies, resource limits, and farm goals should be included in an empirical model of farm family decisions about technology adoption.

Several different types of technologies have the potential for enhancing resource productivity and aggregate food production. In evaluating these technologies, it is important to remember that not all methods may be feasible in all regions of the WASAT. Technologies that have been identified by researchers as holding promise in some if not all subregions of the WASAT include: chemical fertilizers and other soil additives (Pieri; Montgomery) animal traction technologies which facilitate plowing and secondary tillage practices (Nicou and Charreau; Dugue; Jaeger; Barrett et al.); practices that increase crop yields through increased retention of plant available soil moisture such as tied ridges, diggettes, and water pockets (Wright; Ohm, Nagy, and Sawadogo); short season varietal cultivars which hold promise of having greater productivity and less susceptibility to drought than traditional varieties (Norman et al. 1976a; Norman et al. 1976b; Matlon); and finally various methods involving agroforestry (Wright).

The treatment of technologies also requires the inclusion of traditional farming practices, which serve as a baseline of comparison for new technologies. It is especially important to include cereal/cereal and cereal/legume intercropping because adapted technologies will probably be incorporated into such rotations.

Qualitative or quantitative constraints on capital, labor, land, and management may prevent farmers from adopting technologies that enhance factor productivity. Therefore, constraints and coefficients relating to such limits should be included in the empirical model.

A lack of access to capital is a possible explanation for nonadoption of certain productivity enhancing technologies such as chemical fertilizers (Krause et al.). Therefore, paradigms should contain constraints relating to the limits on the availability of capital, to the cost of capital, and to the capital requirements of the various technologies.

Labor shortages or bottlenecks often develop whenever critical labor intensive farm operations such as weeding are done. Research by Sanders and Roth and Delgado and McIntire implies that labor shortages may explain why technologies with the potential to increase yields, such as tied ridges and animal traction technology, have not been widely adopted by West African farmers. Therefore, the model should contain labor use on the various activities and limits on the amount of family farm labor available with a provision for the purchase of additional labor where a labor input market exists.

For land inputs, the problem is primarily qualitative rather than quantitative in nature. Large amounts of low quality land are available to farmers in many areas of the WASAT; highly productive land is in very short supply, however. Cropland productivity is highly variable from plot to plot and it is important that this variability is accounted for in farm decisions (Stoop). For example, land immediately surrounding the village is often of the highest quality because it receives more manure than other cropped areas. Land near the village is often planted in maize and other crops which are relatively responsive to the level of soil fertility. Empirical models should account for the heterogeneous nature of farmland productivity by having several land constraints based on differences in land quality rather than one land use row based on an assumption of homogenous land quality.

A final problem may be the quality of the farm management especially as it relates to farmer experience with new technologies. For example, farmers often experience a learning curve with respect to the use of animal traction using oxen (ATO) methods and may not derive full benefits from such operations until 4 or 5 years after initial use (Jaeger). Unfortunately, introducing learning curves into a programming model may be very difficult, although the curve could be reflected in coefficients derived from primary data.

The final component of the conceptual model advanced here is the possibility that goals besides profit maximization may be important to farm families. The goal of providing an adequate diet for the farm family can be included by either requiring a given level of produced food to go to consumption rather than to market or by tieing consumption to income as is done in Adesina, Abbott, and Sanders.

Risk and Stochastic Modeling

The conceptual model can also be extended to include concepts of risk, uncertainty, and the stochastic nature of farm decisions. Weather, diseases, and other elements that stem from agriculture's biological nature contribute to the uncertain and stochastic nature of farm production decisions. Farmers usually encounter uncertainty when they adopt a new technology because they may be unsure about its performance under their own particular farming conditions. Finally, uncertainty may be due to the large amount of variability that often occurs in output prices and input prices and in the availability of these markets. Empirical models should account for the risk and uncertainty in agricultural decisions provided by all of these factors.

The modeling of uncertainty in agriculture can be viewed in two different ways: 1) traditional approaches to risk and uncertainty; and 2) the stochastic and "dynamic" nature of agricultural decisions. Under the former approach, decision makers are seen as taking "conservative" approaches to decisions with uncertain outcomes. For example, a farm family might reject an option with a high expected (average) return that also has a large probability of a big loss.

Decisions about the adoption of technology are also often of a sequential stochastic nature in that "later decisions are influenced by both earlier decisions and by stochastic parameters whose values become known after earlier decisions but before the later decisions" (Anderson, Dillon, and Hardaker, p. 224). For example, the later decision of whether to fertilize or not fertilize depends on choices about soil use that the farmer made in previous years--the earlier decision--and more critically on the amount of rainfall in the coming year--the stochastic parameter.

Many different methods have been suggested in economic literature for dealing with the risk and uncertainty of farm decisions. Adesina, Abbott, and Sanders examine the effect of farmers' risk aversion, financial liquidity, and limited labor on use of fertilizer in Niger. Rainfall is an important source of production risk relative to fertilizer use in the area because fertilizing generally increases yields in wet years, while often burning crops in dry years. The authors use the Minimum Absolute Deviation (MOTAD) method to account for yield variations in fertilized and unfertilized crops over time. They conclude that farmers with less aversion to risk are more likely to fertilize larger areas of their farm than their relatively risk averse neighbors.

Butcher, et al. also looks at the effect of production risks on the adoption of new technologies such as tied ridges, short season cultivars, and fertilizer use. Historical weather data and a moisture stress crop growth model are used to generate a synthetic time series for crop yields. A focus loss constraint is used to model risk by assuming that farmers would reject any technology with a positive probability of not meeting the farm families nutritional needs in years with low rainfall.

An econometric model is used by Adesina and Brorsen to model the effects of price risks on millet production in Niger. Adesina and Brorsen based their measure of price risk on the deviation of the actual price from the expected price--weighted and summed over a 3 year period--with the previous year's price serving as a measure of the expected price. Model results imply that farmers in Niger respond to price risks in their planting decisions. Increases in price risk for millet caused the amount of acres planted in millet to decrease, while increases in cowpea price risk, which is a production substitution for millet, would cause farmers to grow more millet and fewer cowpeas.

Model Recommendations Relating to Uncertainty and the Stochastic Nature of Farming

We propose the use of a modeling approach originated by Crawford and Milligan that accounts for the sequential and stochastic nature of agricultural decisions. The approach has the advantage of incorporating the long run nature of farm decisions about technology use in the WASAT. An additional advantage of this modeling method is that it can be extended to include risk and uncertainty modeling methods such as a focus loss constraint or a MOTAD set of constraints.

The four basic components of this modeling approach are seen in Figure 2 and consist of a linear programming model subdivided into two parts, Model A and Model B, and two random variable simulation components, SIM1 and SIM2. Model A is a traditional linear programming model where initial planting and early crop production practice decisions are made, as well as projected choices about future crop marketing and other future activities, based on expected yields and prices for the coming year.

The next component in the model (SIM1) is a random number generator that draws from a crop yield distribution, which will be constructed through the use of crop growth models. New crop yield coefficients calculated in SIM1 will be interjected into Model A to form Model B where the farmer will make new decisions based on his initial unalterable choices and the "actual" values derived from SIM1. For example, if SIM1 results indicate that weather conditions will prevent crop establishment on a given field, the farmer will have the opportunity to replant that particular field in the second period, which is analyzed in Model B. Many decisions made in Model A, however, such as choices concerning field preparation, cannot be changed in the second period.

It should be noted that weather variability enters the model through its influence on the distributions of crop yields because greater variability in weather will result in a more dispersed crop yield distribution. Final yield values, i.e., yield levels realized in Model B, are "actual" predicted yields as determined by a random drawn from a crop yield distribution. Variability will influence outcomes in that distributions with greater dispersions will tend to have results (the outcome of the random draw) that are further from the mean of the distribution as opposed to yield distributions with less variability. This treatment of random outcomes contrasts with the usual treatment of yield distributions, where an expected yield equals the sum of each yield outcome in the distribution multiplied by its probability of occurence.

Model B would provide the actual cropping patterns and levels of profitability for the coming year. The results from Model B would be fed into SIM2 where the farm family could make various choices about consumption, savings, and investment decisions. Based on these choices and possibly on various user provided choices about market prices, a revision is made of the initial farm resource endowment which is used for the initial set of runs. The revised farm resource endowment is then used to make a Model A run for year 2 and the modeling cycle is repeated.

For a proper evaluation of new technologies, a long-run planning horizon should be applied to the model. An overall objective function would be imposed on the model in the form of

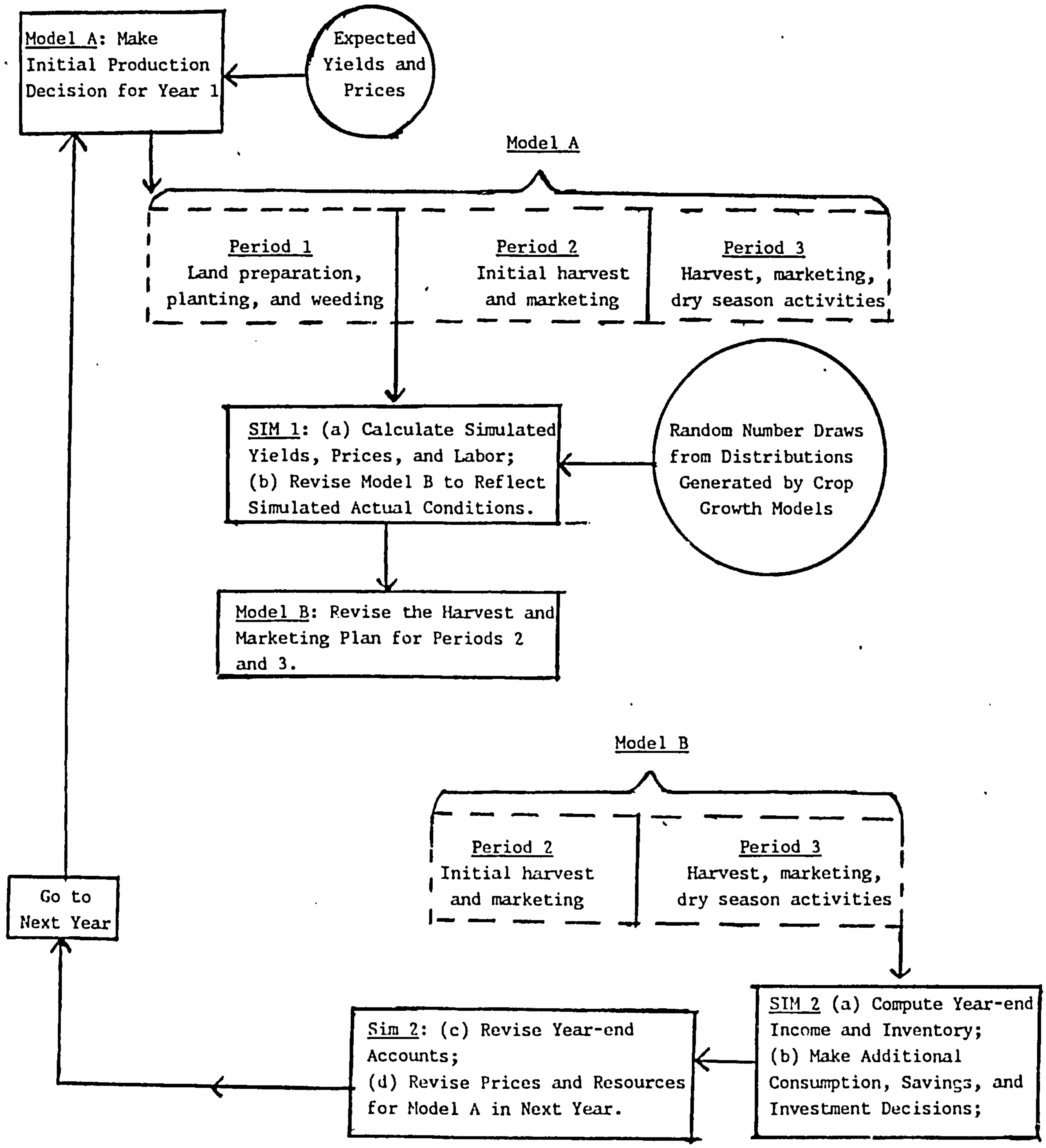

FIGURE 2. Flow Chart of Model Components and Decision Points

SOURCE: Crawford, Eric W. and Robert A. Milligan. "A Multi-Year, Stochastic, Farm Simulation Model for Northern Nigeria: An Experimental Design Approach." American Journal of Agricultural Economics 64(4):728-737, 1982.

$$\text{MAX. } \Pi = \sum_{i=1}^{n} \ell_i \; \Pi_i + \ell_n \, \Delta FA$$

where: Π - is farm "profit" over the farm planning horizon for years $i = 1 \ldots n$,

Π_i - is farm profit in the ith year,
ℓ_i - is the discount factor for the ith year,
ℓ_n - is the discount factor for the nth year (the last year in the planning horizon), and
ΔFA - is the change in the total value of farm assets between the initial year ($i = o$) and the final year of the planning horizon.

By accounting for net returns in each year of the planning horizon, investments in yield-enhancing technologies would be property evaluated. Including changes in the valuation of farm assets would prevent an overvaluing of technologies that depleted such assets--for example, technologies that depleted soil resources.

Several practical as well as conceptual advantages exist for taking this programming and simulation modeling approach. The Linear Interactive and Discrete Optimizer (LINDO) has already been successfully tied to FORTRAN subroutines in a personal computer environment (McBryde) and FORTRAN subroutines for sampling from a given distribution already exist. This method can also use existing crop growth models to generate yield distributions.

Meeting Data Needs

Data needs for whole farm models fall into two categories: 1) data that must come from either the farm level or from experiments performed on test plots; and 2) data that can be provided by crop growth models.

Crop growth models "attempt to mathematically describe the physiological processes of plant . . . growth" (p. 5, Lowenberg-DeBoer, Deuson, and Ensink). Because such models account for the biological and physical factors that determine agricultural production (Musser and Tew), they may be used to show the effect of changes in biological or physical factors on crop yields. Accordingly, such models can simulate crop yield distributions that result from variations in physical and biological determinants of plant growth. For example, growth simulation models are capable of giving yield outcomes under various weather conditions such as drought or when rainfall is plentiful. For our purposes, crop growth models can be employed in constructing yield distributions resulting from random conditions in weather and possible other factors. Crop yield distributions are required for analyzing sequential decision making and risk and uncertainty in WASAT agriculture.

Another data gap that might be filled by crop growth models is the animal feed requirements and the feed value of different crops and different crop varieties. Data on feed values for short season varieties have been especially difficult to find. Information about feed and forage values is critical to the proper modeling of permanent use of oxen tillage methods by farmers in the region.

Certain crop growth models such as the Erosion-Productivity Impact Calculator (EPIC) model have the added advantage of including erosion rates and productivity losses from erosion in the modeling process (Williams, Renard, and Dyke). The EPIC model could aid in the building of soil loss and yield relationships for models of both continuous farming and bush fallow farming.

Using crop growth models will require adjustments necessary for important crops in the region. For example, a model of intercropped sorghum and peanuts for the Sudanian agriclimatic zone in the WASAT will have to be built based on an existing model for other regions and crops. Once constructed, the growth model will be verified and calibrated by comparing model results with experimental data and farm field data.

Other data must be taken from farm-level primary data or from experimental plots. Data needs that must be filled from these two sources include labor coefficients, input costs and output prices, and food consumption by the farm family. Particularly needed is primary data at the farm level for a model of the Sudanian zone in the WASAT.

Conclusion

Economic models can aid political leaders in implementing policies meant to conserve natural resources, increase resource productivity, and hence increase long run aggregate food production. Models that include soil erosion and its effects on soil productivity will allow decision makers to review the effects of policies on resource conservation. We recommend that a mathematical programming framework be used to examine soil erosion under continuous farming and that a dynamic programming model be constructed for examining soil use under bush fallow farming.

A great deal of research exists on farmer use of resource productivity enhancing technologies such as tied ridges. It is important to incorporate as much of this research as possible into a single modeling approach. Also important is a tractable approach to studying uncertainty in farm decision making. We recommend the use of the stochastic simulation model explained in this paper in conjunction with a measure of risk such as the MOTAD approach.

The emphasis in this paper is on information needs and the role of farm-level models relative to resource degradation and farm level adoption of productivity enhancing technologies. It is obvious that a good deal of work remains to be done in these areas. It is still important, however, to begin looking ahead to research needs at the market and social levels and to see how research in these areas can be integrated with models of farm management and resource conservation.

Many studies have noted the problems of marketing surplus food crops and cash crops in the WASAT, for example. Therefore, a need exists for seeing how markets enter into farm production decisions. Another example of future areas of exploration concerns the relationship between the structure of property rights and the movement from bush fallow farming to continuous cultivation. Problems and topics such as these issues must be examined for our modeling efforts to truly aid policy makers.

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