Working Paper

Limits and Consequences of Agriculture and Food Production: A General Methodology for the Case Studies

Duane Reneau
Hans van Asseldonk
Klaus Frohberg

WP-81-015
February 1981

IIASA International Institute for Applied Systems Analysis □ A-2361 Laxenburg □ Austria
Telephone: (0 22 36) 715 21 *0 □ Telex: 079 137 iiasa a □ Telefax: (0 22 36) 71313

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PREFACE

The problems involved in the production and distribution of food in the world is a principal concern of the Food and Agriculture Program (FAP). A set of models, to estimate the effective agricultural production and demand levels in the major producing and consuming nations of the world and to calculate the necessary world price and trade levels if those supplies and demands are to balance, are being constructed as the first task of the FAP. The primary focus in this task has been on policies over a medium term, 5 to 15 years, perspective. The understanding of the policy options that can be obtained from this task needs to be supplemented by analysis of questions concerning the long-term limits to agricultural production and the environmental consequences of various levels or methods of production. Therefore to investigate these aspects of agricultural production a second task was organized in FAP.

After many discussions both within FAP and with outside experts, a consensus was formed that over the long run the level of agricultural production and how agriculture interacts with its surroundings is dependent on the relationship between three sets of parameters that can be conveniently grouped under the headings: resources, technology and environment. It was also agreed that the level and consequences of agricultural production must be studied on a site-specific basis because of the fixed nature of the key inputs of land and solar energy and because the level of environmental effects caused by various agricultural production methods depends on the other uses and potentials of the area in which the agriculture production takes place. Nevertheless, if IIASA was to undertake an analysis of these problems, the investigation must have global implications. Thus it was decided to develop a general methodology but to apply it to particular areas through case studies. This approach would allow the location specific nature of the problem to be recognized while still yielding comparable results. Furthermore, since the case studies will be undertaken by groups within each of the study regions, FAP will be fulfilling the basic IIASA mission of fostering research, collaborating in making that research more efficient and helping to widely disseminate the results.

ACKNOWLEDGEMENTS

We would like to thank Csaba Csaki, John Graham, Jaroslav Hirs, Nikolaas Konijn, Andrew Morton, Kirit Parikh and other members of the Food and Agriculture Program who gave generously of their time and talents in the conceptionalization and formulization of this paper. The patience, diligence, and good cheer of the secretarial staff, particularly Julia Czekierska and Cynthia Enzlberger, who did most of the typing, is to be especially commended.

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Introduction

This paper is one of a series in which the limits and consequences of agricultural production over a long time horizon are explored. A paper by Jaroslav Hirs (forthcoming) provides a general overview of the relationships between agricultural production technologies, resource use, and the environment. Whether the food and agriculture system will be able to meet current and future world agricultural demands is identified as the central question which motivates our examination of these relationships. In other words, what are the important relationships between these areas which will affect the stability and sustainability of the food and agricultural system in the long run. The paper also argues that the analysis must be performed on a national or regional level in the form of case studies because of the location specific nature of some of the key inputs.

The purpose of the present paper is to formulate a general methodology to ensure that the case studies are comparable with one another. Comparability is understood to have elements of both similarity and dissimilarity. To be comparable, the various case studies must be similar in their general outline. That is they must view the problem from the same perspective, and address a similar set of questions. Use of a common modeling approach may further facilitate comparisons. At the same time it is both possible and expected that differences in detail and emphasis will be present within each particular study.

Nonetheless, while it is recognized that each region or nation that will make up an individual case study has some unique features, we believe that all share sufficient common aspects to profit from following a common general methodology.

In order to facilitate the outlining of a general methodology, this paper will be divided into three main sections. A definition and classification section, a section on questions to be addressed, and a section dealing with the proposed recursive dynamic model. The definition and classification section is designed to give a working definition of the region modeled, linkage with the rest of the economy and each of the three aspects of the agricultural system on which the case studies will focus.

The questions section lists, by each aspect, various questions, in general and in particular, that the case studies are expected to answer. The modeling section outlines in block form the proposed model.

1. Definitions and Classifications for the Case Studies.

This paper proposes an outline of the general methodology that is expected to be used for most of the case studies of the task: "Technological Transformations in Agriculture: Resource Limitations and Environmental Consequences". When this general methodology is applied to the specific case studies, certain choices must be made.

1.1. The Study Region

One of the first major choices is of the study region. A region in our terminology is a geographical area ranging in size from a watershed to a small country.

It is assumed that the region to be studied or modeled will be chosen on the basis of certain general criteria. Three important criteria are:

(1) A choice based on geographical and physical characteristics, land capability, water flow system, and climate.

(2) A choice based on the minimization of the aggregation error from an economic point of view. That is picking a region that can be represented by a sample of subunits from it.

(3) A choice based on socio economic criteria such as political boundaries, administrative units, etc.

However the region is chosen it must be agricultural in nature, be an important producing region, and presently or potentially be a source of environmental effects. Beyond these characteristics the size of the region as well as the amount of disaggregation within the region is mainly dependent on the questions posed and is constrained by the manpower and funds available for its analysis. The region must be disaggregated sufficiently that the resulting land units are considered homogeneous in their response to the applied technologies and yield similar amounts of agricultural commodities and side effects for given levels of inputs but the number of units and hence the size of the region can vary widely.

1.2. The Relationship of the Region to the Rest of the Economy.

A further consideration when selecting the region is the linkage of it, in both time and space dimensions, with the remainder of the national agricultural system, the rest of the economy and ultimately to other national economies through world markets. Depending on the size and importance of the region modeled this might be dealt with by:

(1) Assuming that the production and input use in the region modeled has no appreciable effect on the rest of the system. (Only acceptable for a very small region)

(2) Try to select a region which is representative of the whole agricultural system according to the important variables for this study. This implies that the rest of agriculture will change in tandem with the selected region.

(3) If one or two above is not applicable then one must explicitly model the interdependence of the region with the remainder of the economy. This can be done either by modeling the rest of the economy (possibly in aggregate form) simultaneously with the region or by using excess demand functions as a bridge between the two.

Different research resource requirements including manpower, computer time and data base will need evaluation, before the size of the region, number and type of resource adjustment feedbacks, number of environmental effects, and fineness of technological definition is decided upon.

1.3. Defining Resources, Technology and Environment.

Two criteria are used to define resources, technology and environment and to classify the various aspects of agricultural production under this division. These criteria are:

(1) The definition must stress how resources, technology and environment are interrelated in our study;

(2) The classification of the various elements of concern within the agricultural system under this scheme must be done in such a way that quantifiable parameters which allow analytical manipulation within the proposed model will be available.

1.4. Resources

For the purpose of this study resources will be defined as those material inputs upon which the agricultural system operates to produce outputs. Under this definition abstractions which are defined as inputs for some studies such as risk bearing ability, or social norms and customs, will not be considered as resources. These material inputs will be subdivided into natural or primary resources, and intermediate or secondary resources.

There are many natural resources that might be included in a study of an agricultural system; land, water, solar energy, climate, etc. Of these it is expected that the case studies will focus particularly on land, water and labor. Land will need to be included as it is the basic unit for crop production in nearly all agricultural production models. Since it is also expected to serve this purpose in our models, it will be the key primary input. As such, a considerable amount of disaggregation of land types is expected. This disaggregation will need to be based on crop growing capability (i.e. potential yield by crop), technological interaction (i.e. the need for a particular combination of inputs per unit output), and environmental interaction (i.e. the amount of environmental impact). Thus land classes by soil type, slope, slope length, fertility and reclamation level will be included. Reclamation level in this context means the addition of such items as terraces, irrigation or amelioration.

Water will need to be included both to permit consideration of irrigation or drainage problems and to trace the environmental effects on water quality.

As labor we will include only the physical effort of an unskilled or semi skilled worker. Skilled labor or management will require the addition of an appropriate amount of training or education. Labor will be subdivided in some models to consider peak seasons such as planting or harvesting and periods of the year when off-farm employment is available.

It is not presently planned to include directly the effects of differences within a subregion in solar energy and climate either geographically or over time. It is expected that the subregions will be sufficiently small that the climate can be considered homogeneous within each. If this is not considered acceptable it will be necessary to break the area of the case study into homogeneous climatic zones as a part of the modeling process, just as is done with land classes.

Intermediate resources are those which the agricultural sector purchases from other sectors of the economy or trades within the agricultural system. Again any number of items could be considered as intermediate inputs depending upon the particular focus of the study or problem of interest. In general we shall distinguish those which may be limiting in the future or whose use may have environmental consequences. Thus all the case studies should include as intermediate resources:

A) Capital
   (1) Physical Capital
   (2) Human Capital
   (3) Livestock Herd
B) Energy
   (1) Fossil Energy (i.e. oil, natural gas)
   (2) Electricity
   (3) Biomass (fermentable crops or crop residuals, nonfermentable biomass)
C) Fertilizer
   (1) Organic
   (2) Inorganic
D) Biocides
   (1) Herbicides
   (2) Pesticides

Those intermediate inputs having a usable life span of greater than one time period within the production process will be defined in our studies as capital. It will include physical capital such as draft animals, tractors and machinery complements, on-farm irrigation equipment, etc. for crop production and buildings, feeding equipment, pens, etc. for livestock production. Human capital is defined as that amount of additional investment in training and education necessary to change unskilled labor into skilled agricultural labor or on-farm management. It is expected that this input will vary considerably from case to case but its main importance in all studies will be as a major factor in any significant shifts in production patterns or intensity. For this purpose it will not be essential to accurately measure the level of human capital presently available in a study region but only the likely investment necessary for a given change (i.e. the cost per unit change.) The livestock herd or breeding stock will also be considered as capital. These will include the animals kept as part of the livestock production activities. In some studies animals may have dual roles both as draft animals and as livestock production units.

Energy use, especially fossil energy is of great concern at this time. Therefore, it is thought important to include several types of energy: those that are purchased from other sectors, those both produced and used in the agricultural sector, and those that might be produced for sale as output from agriculture. Among purchased inputs we distinguish between fossil energy and electricity. Electricity may include a substantial component of nuclear or hydropower. Therefore the price differential of these inputs may change in the future.

Within the agricultural sector biomass production or livestock byproducts (manure, processing wastes) can be used as energy either directly by burning or indirectly through a fermentation process. As an output the agricultural sector can produce energy in the form of biogas, alcohol or nonfermentable biomass mainly wood.

Closely related to energy as to source both within and outside agriculture is fertilizer. Inorganic fertilizers such as nitrogen, phosphorus and potassium will be purchased from the nonagricultural sector. Organic fertilizers will come from the same biomass or livestock byproducts and compete with or complement the intrasector energy production. No fertilizer production as an agricultural output is planned in these studies. All biocides will be purchased from the nonfarm sector as required.

1.5. Technology

In general technology is defined as the science or study of the practical arts or as the pool of knowledge concerning how to accomplish some task. We shall define it operationally as a set of techniques where a technique is defined as the combination and use of a set of inputs to produce a given output. Furthermore, due to the proposed use of an activity model to describe the economic decision process, each particular set of inputs, the elements of which are combined in a specified way and leading to a particular set of outputs (commodities, byproducts, pollutants, etc.) will be, by definition, a unique technique (i.e. not a continuous function). It is obvious that this definition potentially leads to a very large number of separate techniques. The problem then becomes one of preselecting those that are the most likely candidates by some criteria and then only allowing a choice from amongst this subset. The criteria to be used to pick this "choice set" might include:

(1) Techniques presently in use in the region;

(2) Techniques presently in use in other regions with similar climates and soil types;

(3) Techniques that could be adopted without unacceptable amounts of investment.

Within technological progress we will distinguish between the diffusion of technology that already exists in practice somewhere in the world and innovation of new techniques. Diffusion consists of the process of introduction and adoption of different technologies. It is planned to make this adoption process endogenous to the model as much as possible by having adjustments in the set of available techniques (the choice set) be the result of investment activities. The magnitude and speed of adoption will be constrained in the model by the rate of change in human capital, investments in physical capital and "assumptions" concerning shifts in the economic conditions and social infrastructure outside of agriculture. (These assumptions may be policy variables in some case studies).

The innovation of new techniques deals with a potential breakthrough in agricultural research. Since there is no way to predict the outcome of efforts in genetic engineering and/or construction of new equipment and even if discovered it is unlikely a major change would be widely adopted within the time horizon of the model, we will keep innovation exogenous. However, in the wider perspective, an inventory of agricultural research currently in progress, in order to set up a data bank, has to be considered worthwhile. Nonetheless, while the gathering of such a set of data is being considered as part of the Food and Agriculture Program, it will not be directly connected with the present set of case studies.

1.6. Environment.

One definition of environmental science is the study of human influence on physical processes in nature. Since this paper is only concerned with the production aspects of the agricultural system, we will mainly concentrate on human behavior as it influences the production of agricultural products and how this behavior is likely to affect the environment in which that production takes place. Environmental effects are all those effects external to a defined entity and caused by the activities of that entity. When environmental effects are spoken of, in general, all or a large part of humanity is usually the implied entity of definition. Thus environmental effects have come to mean changes in the larger, mainly physical surroundings such as air, water bodies and land. Because our defined entity is the agricultural production system in a specific region, environmental effects, in this context, might be considered to have social as well as physical components. While this is true overall, and certain social effects such as the often discussed, "landscape effect" might be important in some regions, we will principally deal only with the physical environmental effects and their economic consequences. Also, since the number and type of effects is very broad it will be necessary to consider only a limited subset of the most important.

Within this limited subset the main effects in most case studies will be soil sediment, nutrients and pesticides in the surface water and nitrates in the groundwater. Their level will be affected by the production techniques used, any specific techniques designed to change or ameliorate them and their costs.

The costs associated with each environmental effect will be determined by an environmental cost damage function and/or by the imputed value of a predetermined level of constraint.

2. Questions to be Answered

For each case study we wish to answer specific questions relating to the resource base, to technology and technological change, and to the environment. At the same time we wish to keep the general questions which outline the main purpose for these studies clearly in mind. These general questions deal with the adaptability of the agricultural system to new circumstances, stability of the system when confronted by unexpected shocks and sustainability of required production over the foreseeable future. These questions will serve to orient the methodology to be developed. For simplicity, the specific questions are categorized by resource, technology, and environment even though a particular question may have aspects that cannot logically be confined to one category.

2.1. Resource Questions

Over both the short and long run, questions regarding patterns of resource use for both primary and intermediate resources must be considered.

(1) Resource use over time should be identified. Shifting patterns of resource use both within the primary and secondary resource catagories and between these categories should be traced. It is important to be able to show how the stock of various natural resources within the region shifts as the relative price or availability of intermediate inputs changes, as the demand for agricultural production shifts and as new technology is introduced.

(2) The resources which are most constraining should be identified for each time period, and what effects various investment scenarios have on these constraints.

(3) Long-run changes in resource quality and availability need to be considered. Those short-run effects which the farmer is aware of will be considered within his decision framework. Over the longer run there are also changes that are not within the decision horizon of a single farmer. These changes should be identified and policy options to mitigate their effects tested.

(4) The role of the private (farmer) and public (government) actors and the various options available to each need to be analysed. Tracing the impact of different government policies on farmers' decisions and ultimately on resource use will be an important part of these studies.

(5) The impact of long run and short run changes of the soil structure due to the use of inorganic or organic fertilizers should be studied. There is considerable controversy at the present time as to how much humus must be returned to the soil and how to do it if only inorganic fertilizer is applied. Running a series of model scenarios may allow an estimation of just how important this issue is for sustainable agricultural production.

2.2. Technology Questions

With regard to technology the most pressing questions focus on how and why technology changes. Such shifts can be induced by a change in resource availability and/or a re-evaluation of the importance of various environmental effects. A few of the possible questions which should be considered are:

(1) Questions relating to the time path of technological change, where various labor and capital shifts should be identified. The limits imposed by societal goals on the speed and direction of technological change are important aspects of this question.

(2) Policy makers may be interested in certain macro investment questions and the effect of these on farm level technology choice. These investment options should be specified and analysis done on their impact in the region.

(3) Another question to be answered by this study involves the long term sustainability of different farming systems. The case studies should attempt to identify the technological set or sets which will come closest to making the system sustainable in the long run.

(4) Given that various fossil fuel, electrical and biomass energy resources have been identified, a shift from one energy form to another through the use of a different technology may be appropriate. The effect of a change in the relative price of a particular type of energy on the set of technologies to be used should be investigated.

(5) Since there are trade offs between alternative technologies, resource use and the environment, the critical parameters which affect the balance between them need to be identified. Which parameters have the greatest effect on the stability of the system should be investigated.

(6) The speed with which new technology is diffused in an agricultural system is dependent not only on the investment of the individual farmer but also on social investment such as agricultural education and extention. Various social investment scenarios and how they affect the technology set used in agriculture should be a part of each case study.

2.3. Environmental Questions

Agricultural production and the environment are closely linked. Shifts in resource use patterns through technological changes impact on this environment. Some particular questions may be noted:

(1) Shifting patterns of production induce different rates of soil, nutrient and pesticide loss. The "most desirable" policy or set of policies (taxes, regulations, subsidies, etc.) to internalize the external cost of these losses need to be identified.

(2) In some countries, nutrification of lakes or river systems and nitrate leaching into the groundwater are becoming important problems. In others the amount of water available for agriculture is limited. Therefore, where water quality or quantity is or could become a limiting factor, alternative strategies for effective use of this resource while maintaining environmental standards need to be studied..

(3) Damage functions which attach a value to various levels of environmental effects need to be calculated. On the one hand, it may be desirable to ask which of several policies will result in the least amount of damage to the environment. On the other, what will be the resulting amount of environmental damage given a particular policy. The comparative effects of various policies on the environment should be studied.

(4) It may be desirable to investigate the role of organic and inorganic fertilization practices as they relate to the environment.

The above list is certainly not all inclusive. It merely illustrates some questions that are of interest and that may be evaluated within the framework proposed. Which questions are most important given the particular circumstances of each individual case study will need to be identified within that study. But, due to the fact that once a specific framework is formulated, it precludes answering certain questions which are beyond the scope of the particular model, it is important that the questions to be answered are formulated first. Then the model can be shaped with them in mind.

3. The Proposed Model

Given the definitions of resources, technology and environment as specified above it is thought that the questions of interest can be best analysed with a recursive dynamic model.

The recursive dynamic model we propose will consist of the following modules:

a) Technology generator
b) Physical crop module
c) Physical livestock module
d) Resource adjustment and environmental coefficient generator
e) Interface module
f) Linear programming module
g) Resource adjustment module

A schematic conceptualization of the model is presented in Figure 1. Boxes represent modules while circles represent exogenous or endogenous parameters and variables.

Each of the separate modules emphasizes one of the aspects of agricultural production which we wish to concentrate on or serves to connect the others into a coherent whole. The technology generator organizes and manipulates the information on present and future agricultural technology. The crop and

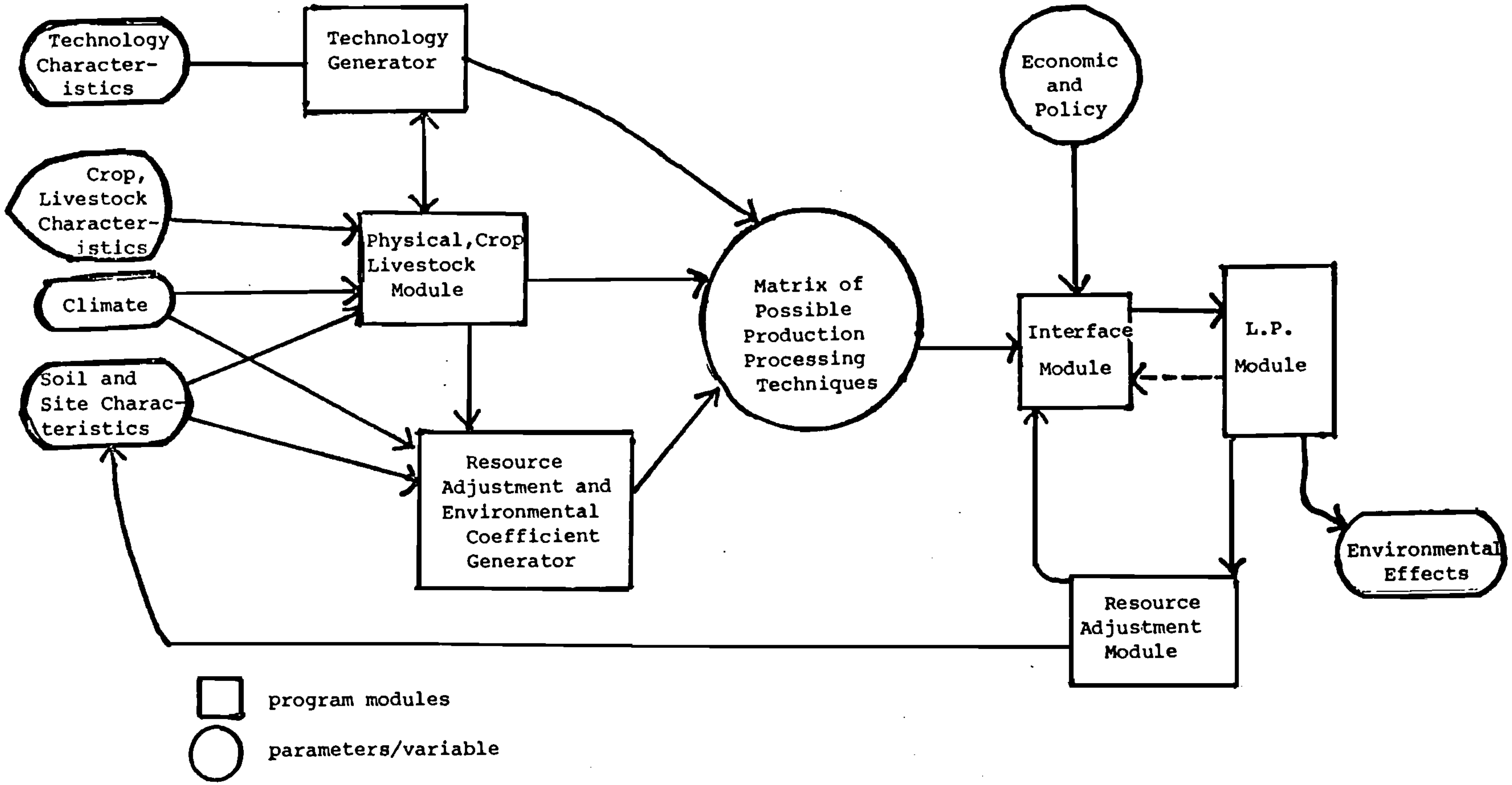

Figure 1. Dynamic recursive model structure.

livestock modules simulate some of the physical processes involved. The resource adjustment and environmental coefficient generator adds possible natural resource change and environmental effects. The interface module organizes the data generated by the other modules into production activities, adds economic and policy information and creates or updates the linear programming matrix. The linear programming module allocates the various resources, and thereby determines the production structure for a given criterion function. Finally, the resource adjustment module specifies what the effects of the L.P. decision are on the resource stocks in the region. Thus by interconnecting separate modules and running them concurrently and/or sequentially, we are able to handle more efficiently the massive amount of, and partially specialized information, different time steps, and various degrees of interaction. This allows us to incorporate agronomic and other physical processes recursively with an economic decision module to trace the changes in the agricultural production in a particular region given various scenarios.

3.1. Technology Generator

An inventory of all current and currently feasible technological production alternatives likely to be available during the relevant time period for the particular case study region will be created with the help of experts in the agricultural sciences. This information will be organized to create sets of inputs for the physical crop and livestock modules and the resource adjustment and environmental coefficient generator. These input sets will thus be combined with natural resource inputs and the resultant commodity and environmental coefficients to generate a matrix of discrete production techniques from which the interface module can draw to create or update the production activities in the linear programming module.

3.2. Physical Crop, Livestock Production Modules

The physical relationship between soils of various types, climate, and different crops will be dealt with in a separate module as will the feed and herd maintenance requirements of the livestock sector. The crop module input data will consist of those individual crop characteristics such as genetic, climate, and soil and site characteristics along with variable and management input sets. The module will simulate the physical processes involved to calculate an expected yield of the main product and associated by-products, for each possible combination of resources and inputs. The livestock module will use data concerning breeding stock characteristics, feed characteristics and management levels to generate livestock requirements and animal production coefficients.

3.3. Resource Adjustment and Environmental Coefficient Generator

Agricultural production is different from most industrial production in that a fixed input, land, is an extremely important input into the production process and one that cannot be easily substituted. Therefore, it is important to take care that production in one time period not be done in such a way that its future productivity is severely reduced. Resource adjustment coefficients will enable the effects of various production techniques on this key resource to be traced so that those effects can be considered in the decision module.

Agricultural production like most production processes creates side effects along with the products of interest. Some side effects have an environmental impact. Furthermore, the level of the side effects produced may differ with different production processes. The environmental coefficients generated will be used to link each production technique to its expected environmental effects. Thus the decision module will be able to consider these effects also.

3.4. Interface Module

The interface module will organize and develop the matrix of technical coefficients for the linear programming module. The data input for the module will include the matrix of possible production and processing techniques as well as policy data and exogeneous and endogeneous economic data. The interface will generate expected prices for, and create, the buying and selling activities. It will preselect a limited subset of the possible production activities for inclusion in the L.P. and it will determine the necessary values for the objective function and right hand side vectors.

The main purpose of the interface module is to coordinate the connection of the physical simulation and coefficient generation modules with the linear programming decision module to facilitate the integration of physical and economic data. It will also handle the mechanical aspects of changes in the L.P. for each time period.

3.5. The Linear Programming Module

As presently envisioned, the linear programming module can be thought of as a single year time slice during which the farm level actor will attempt to satisfy a specified criterion function given a set of primary resources, a choice set of possible techniques, quantities and/or prices of inputs (or their supply functions), a demand schedule for all outputs, and a schedule of expected returns to various investments.

Because none of the questions of interest can be investigated in isolation we must simultaneously consider many input and output variables. Furthermore, large amounts of engineering and agronomic data must be integrated into the decision module along with the economic data. Unfortunately, many of these parameters cannot be estimated econometrically due to the lack of data. Therefore, they must be arrived at through the use of expert judgement. The use of an activity analysis procedure such as linear programming makes it easier to determine the judgemental parameters while allowing the efficient solution of a large and complex activity structure. Also, in connection with a set of modules that simulate the physical processes in agriculture, a linear programming model can be run recursively to test normative future scenarios as resource constraints shift, economic conditions change and technological knowledge is acquired. Thus it was felt that a linear programming module would be best as the economic decision component of the model.

All LP models have three principal parts:

(1) A criterion function which specifies the goals over which optimization is performed;

(2) The coefficient matrix which maps the specified activity list into the set of constraints;

(3) The right hand side (RHS) vector which sets the level of each constraint.

Figure 2 shows a suggested LP matrix structure. This configuration is just a condensed version in blocked format. It should not be considered to be either all inclusive or restrictive but only an example of an LP matrix structure from which each case study will tailor its own.

Activities

Input Acquisition						Crop Prod.				Livestock Product.			Processing					Output		Investment			
Labor	Energy	Feed	Inorganic Fert.	Machinery	Biocides	Food Crop	Feed Crop	Forage	Wood	Ruminant	Non Ruminant	Draft	Feed	Energy	Organic Fert.	Pollution Abatements		Commodities	Pollutants	Natural Resources	Capital	RHS	
						-	-	-	-											-		≥ +	Land
						-	-	-	-	-	-	-		-						-		≥ +	Water
+						-	-	-	-	-	-	-	-	-	-		-			-	-	≥ +	Labor
				+		-	-	-	-	-	-	+	-	-	-		-			-	-	≥ +	Machinery, Draft Power
	+					-	-	-	-	-	-		-	+	-		-					≥ o	Energy
			+			-	-	-	-						+							≥ o	Fertilizer
		+					+			-	-	-	+									≥ o	Livestock Feed
						+	+	+		-		-	-	-	-							≥ o	Forage, crop residue
									+						-							≥ o	Non-fermentable material
										+	+	+		-	-							≥ o	Manure
					+	-	-	-	-													≥ o	Biocides
						+			+				+	+				-				≥ o	Commodities
						+	+	+	+	+	+	+	+	+	+		-		-			≥ o	Pollutants

Figure 2. Block L.P. matrix structure.

Criterion Function

The model is designed under the assumption that all agricultural production decisions are made by the farm level actors. Society expresses its wishes to these decision makers by manipulating (actively by planning, taxes, regulations, investment, etc., or passively through markets) the price or value relationships among the items over which the farm level actors attempt to satisfy the given criterion function. It is further assumed that the criterion function will be an indicator of the goals society wishes the agricultural system to strive for and not only the goals of an individual farmer or the farming sector. That is the farm level actor is assumed to act altruistically given the constraints involved and the value relationships signaled from the other modules.

The linear programming model could be specified using various criterion or indicator functions. One possibility is to maximize net social benefit. This formulation uses the concept of economic surplus as the approximate measure of social wellbeing. The maximization of economic surplus summed for producers and consumers is the solution criterion for the model. This formulation would require the following information:

(a) the variable cost associated with each activity,

(b) a stepped demand function for each output commodity,

(c) a damage function relating the level of each environmental pollutant with a cost added to the agricultural system.

A second criterion function would be to minimize the cost of production of a given level of agricultural output. Pollution damage would be treated in this case as an additional cost component. The output could be prespecified for each commodity. Or instead of specifying commodity wise quantities one can predetermine a value of total output that has to be reached. This allows the model to choose an optimal product mix. Required investment levels could be prespecified or entered as a pseudo demand. To avoid the possibility of infeasible solutions associated with set demand levels, demands, both for output and investment, could be formulated with a penalty function connected with deviation from a desired level.

This approach has the feature that the desired output and investment levels and/or their relative importance must be prespecified. This would change the model structure somewhat, shifting more of the decision making to the interface or resource adjustment modules and making the right hand side constraint vector a very important parameter set. Since the linear programming model is considered to represent the farm level decision, this formulation may be particularly suitable for those economies where the principal production decisions are made at a different social level. Also this specification of the criterion function would simplify linkage with the national models of FAP Task 1 where commodity demand quantities will be generated.

A third possible criterion function is one in which net returns are maximized. Net returns are defined as quantity times expected price minus external pollution damages. The expected prices could be the equilibrium prices generated by the Task 1 model or other specified prices. Again, production costs, pollution damage functions and investment return schedules would have to be calculated, but output demand functions would not be necessary. This specification would be useful when modeling a region that was small enough to allow the assumption that changes in the level of outputs will have no effect on national prices. Thus a single price for each output would be given and only changes within the region, separate from all other regions, would be examined.

Activity Description

It is considered advisable to set up the LP matrix structure in such a way that it will be easy to generate the initial matrix, make the necessary changes from year to year and use the solution output for updating and report generation. One way to do this is to group the various activities by type. The major groups in most case studies will be input acquisition, crop production, livestock production, farm level processing, output selling and capital investment.

Input acquisition will encompass all those activities involved in purchasing energy, fertilizer, biocides, livestock feed, extra labor, etc. These can range from a single buying activity at a set price for an unlimited quantity to a complex set of activities reflecting supply functions for time and/or quality differentiated types of an input. An example of the former might be the buying of electricity at a set price per kilowatt hour where no constraint is expected either on how much can be purchased at one time or when it is available. An example of the latter might be hiring labor where quality and timing of hiring is important and different prices would prevail as more is hired.

Crop production activities in the model may be considered in the form of crop rotations. These rotations could initially be derived from historically observed patterns but deviations and completely new patterns would be considered as technolocial change is introduced over time. Crop activities may be further broken down into appropriate conservation and tillage practices. Each crop production activity will require inputs such as land, water, fertilizer (organic or inorganic), biocides, labor and machinery and/or draft animal time. As outputs there may be such things as grain, forage, biomass, soil erosion, nutrients and/or pesticides in the surface runoff and nitrate leached.

Livestock production activities will include both the levels of husbandry and feeding. Feed requirements can be broken up into maintenance needs and into those which relate to yield. Where it is desirable, activities may be added for various age classes of livestock. Each livestock production activity will require inputs such as breeding stock, feed, water, labor, equipment and buildings. As outputs there may be meat, milk, eggs, by-products and manure.

Another set of activities are those relating to processing. Within processing we will include activities that transform some of the outputs of the crop and livestock production activities into agricultural inputs or into outputs such as alcohol. Processing activities may also include pollutant amelioration or abatement activities such as catch basins or settling ponds in some case studies. Processing of food or animal products for final demand will not be considered for all commodities in most models. The purpose of processing activities is to emphasis intra-agricultural connections between standard agricultural commodities and their joint products and not to attempt to model the complete food chain. Thus only the processing normally associated with farm production or processing with important feedback effects on resource availability will be modeled.

The output activities section will include all the outputs leaving the agricultural system, both the commodities normally thought of as agricultural products and environmental effects. As far as possible commodities should be aggregated to conform with the FAP commodity list used in the national models to simplify any linkage with those models.

The investment activities section will include all the farm level investment decision possibilities. This section of the L.P. model will vary in size and importance in the different case studies depending on how the criterion function is specified and on the importance of farm level decision makers within the agricultural system being modeled. If the farm level decision makers are assumed of major importance in longer run investment decisions then those decisions, with their expected present value will need to be included in the L.P. model. On the other hand, if most long run decisions are assumed to be made at a different societal level then most of the investment choices will be made outside the L.P.module in the recursive component and only the effects will be transfered to the L.P. module usually as changes in right hand side variables.

Right Hand Side (RHS) Variables

The items listed here can be conceived of as either being constraints or accounting rows.

Since land will be subdivided into various classes by soil type, slope, slope length, fertility, and reclamation level, a constraint on the maximum quantity available of each particular class will be needed. Reclamation includes investments such as irrigation or drainage systems, terracing, leveling, clearing or other items that change the crop or livestock supporting characteristics of land.

Labor constraints will be subdivided into peak seasons as appropriate and skilled and unskilled labor.

Capital constraints will include animals, buildings, tractors, machinery complements, combines, irrigation systems, and, if necessary, farm infrastructure.

Fertilizers will be broken down into inorganic and organic types. Also various pesticides and herbicides may be considered.

As an input, energy may be subdivided into fuel and electricity. Transfer rows for manure, and other animal by-products, fermentable crop residues and other crop residues as well as alcohol and biogas will be included to connect the production and processing activities.

Feed requirements for livestock should be subdivided into ruminant and nonruminant categories. Ruminant feeds may be broken down into maintenance and yield dependent needs. Ruminant needs will be formulated in terms of dry matter, protein and energy, while nonruminant needs will be formulated in terms of protein and energy alone. Besides being usable as feeds some crop residuals will also be allowed to compete as a source of fuel or organic fertilizer.

The side effects arising from the production and processing activities within the agricultural system will be separated into two categories; those which directly affect the long term sustainability of the agricultural sector (resource adjustment effects), and those which have external effects. Among these external effects, environmental damaging outputs, such as, soil sediment, nitrogen, other nutrients, and biocides in the surface or groundwater should be considered in those case studies in which they are important.

Resource Adjustment Module

The production activities chosen in the L.P. module will have attached to them coefficients that specify changes in some parameters of the land resource. How these parameters effect the quantity and production capacity of the various land classes will be dealt with in the resource adjustment module. Furthermore, investment decisions will enhance the resource base. Investment behavior is assumed to be based upon the current and past states of assets (land, livestock and other capital) and expectations about future economic and other conditions.

Other Possible Modules

Since most case study models will be used at some point to test various scenarios dealing with externality internalization, government investment in infrastructure, product price policies, etc., it is important to build a model that allows changes in key parameters or variables to be made quickly and simply. This may require the design of a special policy module which controls these variables and parameters. This is especially true if it is assumed that many of the important decisions concerning investment are made at a decision level other than the farm level based in the L.P. component.