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INTEGRATED RURAL/SPATIAL DEVELOPMENT: ELEMENTS OF SYSTEMS ANALYTIC APPROACH

Edited by

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II. RESOURCES

AN INTRODUCTION

Jan W. Owsinski

As mentioned earlier, agriculture is assumed to be the basic activity within the rural socio-economic system. This activity relies heavily upon such natural resources as: soil, water and sunlight. Their interrelation in a given season and over a longer period of time is therefore decisive for the shape of agricultural activities, unless a heavy input of man-made production resources, such as fertilizers, machines, irrigation etc.is made. The latter,however,does not diminish importance of natural resources and their characteristics, it mainly changes the nature of their influence. Thus, for instance, a short-term important increase of fertility and yields through massive use of fertilizers, pesticides etc. may have detrimental longer-term effects, depending upon relations of natural resources or production factore on site. Another example is provided by drainage schemes which, over medium-term time horizon, may add to arable land available some swampy or marshy areas, but over a longer time period could lead to desiccation of the sorrounding region.

Since it is quite common that development entails changes in actual input composition of resources used in agricultural production, the capacity of forecasting consequences thereof is of primary importance in outlining development course. For that purpose formal methods are used, including mathematical and computer modelling. A short overview of these tools is given in the subsequent paper.

THE USE OF MATHEMATICAL MODELS TO STUDY NATURAL RESOURCE ASPECTS OF RURAL DEVELOPMENT

V. Svetlosanov*

Abstract

The use of the econometric, programming and hybrid models in the field of agriculture is considered. The foundation of construction of these models is the linear programming. Usually these models do not include environmental consequences of the land use. The approach including environmental consequences in the hybrid models is discussed. The problems of aggregation and disaggregation are approached on a regional level. In this case the model region must be constructed and the characteristics of this model region must be calculated. The Universal Soil Loss Equation was suggested to evaluate the total annual regional erosion of the model region.

Keywords: model, environment, region, land, use.

The population growth and the increasing food commodities of the people led to the intensification of land use. Optimal management of the land is a very important problem and a lot of questions arises here. What is the optimal land use? What types of crop production and what size of the areas of these crops are to be? What management are to be used for these crops? How to calculate the depletion of the soil? The list of questions can continue here.

Mathematical models may be a useful tool to answer some of these questions. Nowadays a big number of different models have been developed in the field of agriculture. The methodology, size, scope, and time step of these models are different. These models are constructed to analyze the agricultural system's reaction to different anthropogenic policies during a chosen period of time. It is known (Boss, et al. 1977) that over 650 agricultural models were developed for different purposes. They embrace all

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hierarchical levels: global, national, regional and field, and the different time horizon from one year to fifty years are considered. Some of the models are described by many equations and some with only a few. A single crop and a series of crops are included for consideration of the models.

When one consider the agricultural problems on the national or regional levels for policy analysis, the econometric models and mathematical programming models are used very often. Let us consider the main features of these models. There are the structural differences between econometric and programming models. Usually econometric model consists of N independent regression equations:

$$Y_{it} = F_i(Y,Z,A_i) + l_{it} \quad ,$$

where Y - means all possible endogenous variables in equation i;

Z - denotes all exogenous variables;

A_i - means all regression coefficients in F_i;

l_{it} - denotes an error term for regression equation i.

All deterministic programming models have the same structure. They contain the objective functions and a set of different constraints. The main purposes in using the programming models are to choose the optimal agricultural policy, which includes different system's restrictions. This policy is a function of the land use, production structure, technology, environment, labor use, and so on.

In general form a linear programming model can be written (Economics and the Environment, 1977) as:

$$\text{maximize } Z = \sum_{j=1}^{n} C_j X_j \quad ,$$

with the following constraints

$$\sum_{j=1}^{n} a_{ij} X_j \leq b_i \quad , \qquad X_j \leq 0$$

where i = 1, ...m.

Here C_j - the weight coefficients of the X_j - component.

a_{ij} - the requirements of the resource i per unit X_j - component.

b_i - the resource availabilities of the i resource.

The constraints can consider the land availability, the crop production alternatives and the environmental aspects.

The models take into consideration the crop rotation, tillage method, and soil conservation practice. The environmental restraints in the models are very often connected with the limits on gross erosion. The first step here is the determination of the absolute limit on gross erosion per acre cropped. But this step is correlated very closely with soil management, environmental characteristics such as the condition of the soil, slope, drainage, crop yield, etc.

The linear programming model (CRAM) was used at IIASA to investigate on a regional level the concrete agricultural areas with the participation of Bulgarian and Polish Institutes (Albegov, 1979). But this model did not consider the environmental consequences of the land use. In recent years, some attempts were made to develop the hybrid models which include both types of econometric and programming models (An Econometric-Programming Model for Agricultural Policy Analysis, 1980; A Recursive Adaptive Hybrid Model for the Analysis of the National and Interregional Impacts of Three Alternative Agricultural Situations for 1981-83, 1981). Such approach gives the possibility to extend the analytical capability of the investigation from a pure economic problem to the analysis which includes many agricultural and environmental aspects. The hybrid models can be used for policy analysis at the regional and national levels. Usually the hybrid models have one year as a time step. During this period of time the hybrid models are static. The estimation of the model parameters is made every year by applying the econometric models.

By using the hybrid models, the agricultural policy of the land use may be calculated for a long period of time. The hybrid models can be a very useful tool for the land use. In analyzing the result of the land use for a long period of time, one must pay attention to the increasing environmental consequences. The main problems here are connected with the soil erosion, nutrient loss, nitrate leaching into the groundwater, salinization, waterlogging, and so on. All these complicated processes can be reflected in the hybrid models by special coefficients. The control of the environmental consequences is necessary in particular, because the increasing fertilizer use leads to water pollution from the agricultural fields and the depletion of the soil leads to the decreased production of crops. The problem here is how to describe in a proper way all environmental consequences of the agricultural system? One of the possible ways is to introduce the environmental restrictions into the hybrid models. The problem is that the concrete values of the restrictions are connected with the land use and must be checked by special environmental models. It means that the hybrid model must contain three parts: econometric, programming, and environmental models.

Let us now consider the environmental consequences of the land use. The physical nature of the above-mentioned environmental consequences is very complicated. One can clarify the consequences by considering the agricultural field models.

At present there are no perfect and universal complex models which embrace all these consequences. Only four models are the most complex, which consider the hydrological, erosion/sediment, pesticide, and chemical pollution blocks (Haith, 1980). All these models are developed for different purposes, some of them are:

(1) the estimation of the water pollution which is a result of the agricultural production,

(2) the calculation of the possible consequences of the environmental influence to the future agricultural production.

The importance of the second purpose is getting clear especially for a long period of time. The above-mentioned field level models are usually very detailed and consider many natural processes: rainfall, deep percolation, runoff (surface and subsurface flow), erosion, sediment transport, removal of nitrate soil by leaching from percolation, by denitrification and by extraction from the plants. All these processes are considered together with the climate (radiation and temperature) and soil characteristics, topography of the slopes, the crops, management of the land use, and use of fertilizers. The notion of "homogeneity" is a foundation for logic construction of the field level environmental methods. It means that a composition of the soil is homogeneous, the distribution of the precipitation is uniform all over the field, there is the same crop and the same management practices applied. Being very detailed, these models need a lot of information which include both the initial conditions and the coefficients of the models. Some parameters of these models are defined by the empirical way. Some of these models have the validation studied and some do not have (Haith, 1980).

Runoff is one of the important outputs from the hydrological block of the field level models. In general, runoff is a very complicated function of the rainfall, soil moisture, and land use. One of the possible ways to evaluate the runoff is the USDA Soil Conservation Service (SCS) curve number system (U.S. Soil Conservation Service, 1972). This parametric method represents runoff compared to total storm rainfall as a set of curves which depend on soil condition, soil moisture, and practice of man. Peak rate values of runoff was used as an input to calculate later the erosion process. The Leaf Area Index (LAI) method (Ritchie, 1972) was used to estimate the evapotranspiration.

Let us consider briefly the erosion/sediment block. The physical picture of the erosion processes is the following. The soil particles are detached by the raindrops and runoff catch them. The erosion process depends on the condition of the soil, impact of raindrops, and morphology of the slope. There is such process in the points of field. A field contains a lot of the point measurements and represents the first level of the space aggregation. In the field level models there is no time aggregation. Usually the time step is very small in the agricultural field level models, sometimes it is measured by the hours and sometimes by days. The pollution from the agricultural fields is defined by the chemical block. The chemical block usually is the most complicated one in the model. Very often the models consider only the nitrogen and phosphorus cycles in the agricultural fields. In agriculture these cycles are very complicated. The nitrification and denitrification processes influence the field nitrogen. Runoff takes off some part of the nitrogen from the field level. The other part of the nitrogen can be leached. Most of the nitrogen is removed from the fields by the harvest of plants.

Another environmental effect is connected with the problem of salinization for irrigated agriculture. Some models describe these processes (Economics and the Environment, 1977). The foundation of these models relies on the mass balance for water and salinity.

All models which are mentioned now refer to a field or a watershed level. The field level models are the example of the first order of the solution of space aggregation problem, because in reality there are no pure homogeneous fields. In the field environmental models, one can find aggregation from the measurement point to field generalization. The first order aggregation gives us the chance to use physical laws and regularities. In certain cases where there are no physical laws or regularities, statistical relationships on the basis of field observations are used in the field level agricultural models.

At present IIASA is very interested to investigate the environmental consequences of agricultural products on a regional level. Nowadays, there are no mathematical models to calculate the environmental effects on the regional level. The first problem here is the aggregation over space and time. We think that at least two approaches may be advanced and considered to evaluate these environmental problems on a regional level.

The first approach is the following: in principle, any region may be divided into many small homogeneous areas to which the field level models can be applied. In order to calculate the regional environmental problems by such way, in practice, the measurement of the big set of additional information, which the field level models need must be made. The procedure of the measurement is very expensive and needs a lot of time. As a result the effect of the detailed information of the field level model is a washout on a regional level.

The second approach consists of division of the region on some parts and the creation of the model region. Here one faces a special problem of time and space aggregation. To solve this problem the different fields which have the characteristics of soil, climate, crops morphology, etc., must be joined together and characterized by the average values. As a result the region will be represented by only several different areas. The size of these areas can be rather big and exceed the size of the field. The first question here is about the possibility to use the field level models to such big area models. Analysis of the statistical data of the field level model CREAMS (Knisel, 1980) has showed the restrictions for application of this model. Some mathematical expressions of the CREAMS model rely on the concrete field level data. The consequences of it is that this model can be applied to a certain (not too large) size of the areas. Besides the field level models used very detailed information which concern with morphology of the field slope, every day (or hours) precipitation and temperature, physical properties of the plants, the soil construction, the use of fertilizers, and so on, but the regional level models do not need such detailed information.

The output of the regional agricultural model may differ. First of all it depends on the problem. Let us remember that we are going to join together three types of models in the hybrid model and use the time step of one year. So all the characteristics and parameters of the hybrid models must be evaluated as average annual values.

Suppose we are interested to evaluate the total annual regional erosion. As mentioned before, first of all the model region which consists of some big relatively homogeneous areas must be created. The Universal Soil Loss Equation (USLE) can be used for prediction of the average annual soil loss (Wischmeier and Smith, 1965).

$$A = R \cdot K \cdot L \cdot S \cdot C \cdot P \quad .$$

Here, A - is average annual soil loss per ha,

R - is the energy of rainfall,

K - is the soil erodibility factor,

L - is the length of slope,

S - is the average angle of slope,

C - is the cover of the slope,

P - is the management practice.

There are no difficulties to evaluate the parameters of this equation and calculate the average annual soil loss. The Universal Soil Loss Equation represents the aggregation over space and time. Now there are the modifications of this equation (Foster et al. 1973). A concrete value of the regional erosion estimation must be used in the hybrid agricultural model.

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