ECOLOGICAL OPTIMIZATION MODELS

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The paper deals with general principles of mathematical modelling ecological agriculture. Basic assumptions for modelling ecological farm functions are defined and ecological optimization models, their construction and computerization explained. This permits the choice among feasible technologies and decision making considerate for both the environment and economic prosperity.

ecological/alternative agriculture; ecological linear programming model; economic objectives; objective function; linear functions; static model; deterministic characteristics; activities; model constraints

INTRODUCTION

Protection of the environment has become a serious problem for the management of individual enterprises. This problem is particularly outstanding in agriculture due to its objectives and role in national economy. Governments struggle to support and develop ecological (alternative) agriculture which represents a lasting well-balanced agro-eco-system based on local renewable resources. It is a matter of introducing non-conventional farming systems with positive effect on environment and quality of agricultural commodities produced and food-stuffs. Since it is essentially the question of optimizing farm production with emphasis on the dynamic equilibrium of the eco-system, it becomes advantageous to use mathematical modelling techniques which permit experimentation on the model and verification of hypotheses about the reality represented by models.

Before deciding about productive activities of ecological farming a number of questions about production, ecology, marketing, cost, etc. has to be answered. This calls for economic analysis with a lot of calculations. Comparison and evaluation of various feasible solutions can suitably and easily be executed if mathematical models and computers are used.

The purpose of this article is to show possibilities of static linear-programming models in optimizing productive ecological systems, i.e. how to find a production program which would respect ecological principles and ensure prosperity to the farm. Initiation and extension of ecological farming require not only considerable changes in farms themselves but also a new way of thinking and understanding the rural reality and the concept of economic efficiency and quality.

CONCEPTUALIZATION OF THE MODEL

Any mathematical model is an intentionally simplified representation of reality adequate to the purpose. Formulation of suitable models, however, calls for good knowledge not only of modelling techniques but also for up-to-date technologies. Some issues related to ecological farming are therefore to be mentioned first.

Barrier to expansion of this type of farming is caused by an increased risk concerning entrepreneurial profit, technological, economic and ecological restraints, limitation of land convenient for bio-production, etc. Encouragement, on the other hand, is represented by government assistance (legal protection of ecological farming, subsidies, tax reduction), growth of the demand for bio-food-stuffs and increasing concern of the public with environment in general.

Basic principles of ecological farming have to be expressed straightforwardly in the model constraints. In a mixed type of farming, these must reproduce complete material cycles with minimum purchases of feed, seed and fertilizer. They have also to follow ecological peculiarities of the spot and respect the existing bio-corridors. Among other principles of ecological farming, stress should be laid on rational, adaptable and well-balanced crop rotation with an increased share of pulses. Mixed cropping which protects soil against erosion and recirculates plant nutrients, is important to practice. In plant nutrition, fertilizer inputs from the outside are minimized and recirculation of plant nutrients inside the system are maximized. Soil-systems are fertilized rather than individual crops.

The usage of nitrogen fertilizers and crop-protecting chemicals is reduced, if possible eliminated. Most considerate cultivation and rational harvesting technologies are practiced. In animal production, apart from gentle treatment of animals, more variability of breeds, instead of specialized highly productive breeds, is recommended. Effort to meet natural needs of animals calls for unlimited access to fodder and abundant pasture. Animal reproduction is realized through closed herd turnover.

Economy of ecological farming has also to be taken into consideration. Profit maximization is not necessarily the first priority of ecological farms, although they have to do well, i.e. to make profit. They operate in competitive surroundings but have crop yields dropped by as much as 40%; though yields improve and stabilize later on, they still remain by 10 to 20% lower as compared with traditional farming. Prices of bio-products at the market, up to now, have been no higher than those of traditional products. There are no reliable data for a detailed analysis of the ecological farm economy, since the new type of farming has only started.

STRUCTURE OF THE MODEL

It should be made clear at the very beginning that the use of optimization models in the system conception of linear modelling is not directed primarily towards finding an optimum state of the system, but towards clarifying linkages and relations among the system elements and towards understanding the system reactions to changes of the model parameters. Such information is needed for management and improvement of the system functioning.

The optimization model specified below is rather simple, but it meets its purpose satisfactorily. Assumption that relations among model elements are of linear type, simplifies strongly the reality. On the other hand, this enables to use simple and well developed mathematical tools. In addition, as it is known, non-linear functions can easily be approximated by a set of linear functions.

Static nature of the model, where time is not taken into account, brings about a simplification in the sense that the subsequent stages of the system are disregarded. The following cycles of the productive process are assumed, in a static model, to be at the same level, starting with the same stock of intermediate input commodities, with the same structure of productive activities, without any need for new investment, etc.

Although the agricultural production process is obviously of stochastic type, the use of stochastic models would be too sophisticated and difficult. That is why individual model parameters are supposed to be constants. Deterministic character of the model is partially suppressed in the phase of post-optimization analysis where effects of individual parameter changes are studied. Experience proves that this type of a model has a very good informative value.

The structure of the ecological optimization model in general is shown in the scheme (Tab. I). The model contains decision variables with real activities, quantifying productive processes of crop and animal production, the so called removing activities, also with decision variables, quantifying direct

I. General scheme of the model

Constraints	Type of Activity					
	crop production	direct sales of crops	feed	animal production	sales of animal production	economic indicators
Technological	unitary and ratios					
Balance of organic matter and of nutrients	production and consumption coefficients			production coefficients		
Distribution of crop production	yields	unitary coefficients	conversion coefficients			
Balance of feed and nutrients			conversion and unitary coefficients	consumption norms		
Stable capacity				average livestock number		
Balance of animals				herd turnover coefficients	unitary coefficients	
Ecological constraints	ratio coefficients					
Economic constraints	coefficients of cost, revenue and profit					unitary coefficients
Objective function	cost coefficients					

sales of crops, animals, and animal products, and various technologies of exploitation and conservation of feed and finally slack variables, quantifying selected economic indicators.

Mathematical form of the model

Let $m_1 < m_2 < \ldots < m_{13} < m$
and $n_1 < n_2 < n_3 < n$

Minimize linear function

$$z = \sum_{j=1}^{n} c_j x_j \qquad \ldots \text{ MIN.}$$

where: c_j - cost per unit
x_j - level of realizing activities

Subject to following constraints:

$$1. \quad \sum_{j=1}^{n_1} x_j \left\{ \begin{matrix} < \\ = \\ > \end{matrix} \right\} b_i \qquad i = 1, \ldots, m_1$$

where: x_j - area sought of j-th crop
b_i - limitation of the area

$$2. \quad x_j \left\{ \begin{matrix} < \\ = \\ > \end{matrix} \right\} k_j \sum_{j=1}^{n_1} x_j \qquad j = 1, \ldots, n_1$$

where: kj - maximum/minimum share of j-th crop in arable land

$$3. \quad \sum_{j=1}^{n_1} a_{ij} x_j \leq b_i \qquad i = m_{1+1}, \ldots, m_2$$

where: a_{ij} - supply of organic stuff per unit
b_i - resource of organic matter

$$4. \quad \sum_{j=1}^{n_1} a_{ij} x_j - \sum_{j=n_{1+1}}^{n_2} h_{ij} x_j \geq 0 \qquad i = m_{2+1}, \ldots, m_3$$

where: a_{ij} - yields per hectare
h_{ij} - ratio coefficients
x_j ($j = n_{1+1}, \ldots, n_2$) - quantities of feed

$$5. \quad \sum_{j=n_{1+1}}^{n_2} a_{ij} x_j - \sum_{j=n_{2+1}}^{n_3} d_{ij} x_j \left\{ \begin{matrix} < \\ = \\ > \end{matrix} \right\} 0 \qquad i = m_{3+1}, \ldots, m_4$$

where: a_{ij} - content of aliments in unit of feed
d_{ij} - aliment supply per year
x_j - livestock number ($j = n_{2+1}, \ldots, n_3$)

6. $$\sum_{j=n_1+1}^{n_2} x_j - \sum_{j=n_2+1}^{n_3} f_{ij} x_j \geq b_i \qquad i = m_4+1, \ldots, m_5$$

where: f_{ij} - feed supply per year
b_i - feed provision

and $$\sum_{j=n_1+1}^{n_2} x_j - \sum_{j=n_2+1}^{n_3} f_{ij} x_j \leq b_i \qquad i = m_5+1, \ldots, m_6$$

where: b_i - purchased quantity of feed

7. $$k_j x_j \leq b_i \qquad i = m_6+1, \ldots, m_7$$

where: x_j - number of milking cows
k_j - pasture area per milking cow
b_i - total area of pastures

8. $$h_j x_j \leq b_i \qquad i = m_7+1, \ldots, m_8 \quad j = n_2+1, \ldots, n_3$$

where: x_j - livestock number
h_j - conversion coefficient
b_i - stable capacity

9. $$0 \begin{Bmatrix} < \\ = \\ > \end{Bmatrix} - x_j + \sum_{j=n_2+1}^{n_3} a_{ij} x_j \qquad i = m_8+1, \ldots, m_9$$

where: a_{ij} - ratio coefficient calculated from animal turnover

10. $$\sum_{j=1}^{n_2} a_{ij} x_j \leq b_i \qquad i = m_9+1, \ldots, m_{10}$$

and $$\sum_{j=n_2+1}^{n_3} d_{ij} x_j \leq b_i \qquad i = m_{10}+1, \ldots, m_{11}$$

where: a_{ij} - labour input per hectare
d_{ij} - working time for treating one animal
b_i - available working time in busy season

11. $$\sum_{j=1}^{n} a_{ij} x_j \geq b_i \qquad i = m_{11}+1, \ldots, m_{12}$$

where: a_{ij} - price of production unit
b_i - request for sales

12. $$\sum_{j=1}^{n} d_{ij} \leq b_i \qquad i = m_{12}+1, \ldots, m_{13}$$

where: d_{ij} - input cost of a production unit
b_i - limitation of the cost

FORMULATION OF MODEL CONSTRAINTS

While formulating the model constraints, ecological points have to be considered in each of them. The group of agro-technological constraints includes usually a balance of arable land and of meadows and pastures. Crop rotation has to be specified so as to ensure that defined proportions among individual crops are maintained, i.e. to ensure their shares of arable land. This is mostly done by defining upper and lower limits of land for individual products.

A balance of organic matter, in which resources should meet needs, has to be specified next, as well as a balance of plant nutrients N, P_2O_5, K_2O, MgO. Nutrient consumption should be compensated from natural resources, mainly with animal manure, green manure and post-harvest organic remains. Only a limited part of plant nutrients can be supplied with allowable chemicals.

Constraints in the form of balances specify the distribution of plant products by means of distributive activities; they distribute the total crop production to intermediate consumption and to final output.

Balances of nutrients and individual feeding stuffs constitute another important part of the model. Advantage of moving rations is taken and minimum share of a certain feed-stuff in the ration fixed for the whole cycle while the rest of supply is to be calculated. Pasture is the basis for fodder rations in fodder balances. Straw is not considered since it is assumed to be used as litter or ploughed over. Production of associated crops can be regarded as a feed provision and neglected in the balances.

Livestock numbers have to be limited in line with available stable capacity and closed animal turnover by using the balance of weaning animals.

As mentioned already, ecological requirements are reflected in the whole set of model constraints. Some requirements, however, such as those relating to soil erosion, soil contamination, etc., can be formulated by specific constraints which would supplement the classical model.

As also mentioned, certain doubts can take place, while formulating economic constraints, due to the fact that ecological principles are given priority which is contradictory to traditional economic reasoning. Ecological farming must reach a certain profitability in spite of lower yields and productivity. It follows from this fact that higher proficiency and more experience are needed for running an ecological farm with success.

The purpose of economic constraints is to adjust the material inputs and labour cost with income and profit. There are certain modifications in the expenditure structure, as compared with traditional farms. Expenditure on fertilizer and other chemicals get down and the cost connected with their application can practically be neglected, while expenditure on fuel, lubricants, electricity and other energy go up as well as labour cost, due to increased bulk of manual operations.

Decision about the purpose and definition of an appropriate objective function are of great importance. Objective function evaluates different feasible solutions of the linear-programming problem in the quality of an efficiency indicator. Any modification of the objective function modifies essentially the whole analysis. In a single objective function model a complex criterion of global optimality is needed. Profit maximization, fully adequate for traditional type of farming, is not adequate for ecological farming. That is why minimization of inputs while keeping the planned outputs is rather recommended. A more advanced but more sophisticated and difficult approach to this problem is represented by a model with a set of objective functions at a time. Solution of such models requires the vector optimization.

CONCLUSIONS

The above shown model is being tested on the establishment of the University of Agriculture, Prague, where ecological farming is being introduced at the farm of Pozary. There are some difficulties with background information since no experience with this type of farming is available. The farm of Pozary is designed as a model-object of ecological farming because a training and information center engaged in extension activities related to this farming system is badly needed. Transformation of traditional farming into ecological one is being implemented in line with the project conceived by Dr. Bovin from the Institute of Ecological Farming, Sweden.

The purpose of the model is to define more precisely the productive processes on the farm as a whole using facts and figures and to enable evaluation of economic issues and decision making in respect to ecological principles. The model is intended to improve and facilitate the recognition of the farming unit from various views and to permit the assessment of the significance of possible interventions in the economy and ecology of the farm.

Background input data for the model include observations of crop production and animal production with consideration of biological and economic aspects. Biological characteristics of the crop production depend on climate, soil and ecology, on seed quality and fertilization level. Biological characteristics of the animal production depend on type of breeds, applied feeding technology and the treatment of animals. Ecological conditions are featured by prescriptions, regulations and principles of ecological farming. Economic indicators result from yield levels and prices of bio-products, input cost and administrative arrangements.

The model provides output information such as data on areas of cultivated crops, their gross production and distribution, about surplus or deficit of feed stuff, about livestock number, total animal production, etc. Among economic indicators, data on income, expenditure and profit from agricultural activities should be mentioned. In general, the model provides complex information about the production structure of the farm following ecological principles. In the course of experimentation with the model additional data can be derived such as data on influence of market prices on the farm economy, etc. Information provided by means of the model meets the need for qualified decision making.

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Při volbě výrobního zaměření podniků zabývajících se alternativním zemědělstvím je třeba zodpovědět celou řadu otázek ekologických, výrobních, odbytových a ekonomických. Vyžaduje to provedení řady ekonomických úvah, výpočtů a kalkulací. V podstatě jde o snahu po optimalizaci zemědělské výroby, zdůrazňující dosažení dynamické rovnováhy ekosystému. Proto je výhodné pro získávání potřebných komplexních informací využít optimalizačního modelu.

Ekologický optimalizační model, jehož matematická funkce je uvedena, vychází ze základních principů alternativního zemědělství. Jde o lineární statický model, přičemž při formulaci omezujících podmínek se ve všech podmínkách promítají ekologická hlediska. Důležitou podmínkou je bilance organické hmoty a živin odebíraných rostlinnou produkcí. V živočišné výrobě se podrobně bilancují živiny a jednotlivá krmiva s ohledem na pohyblivé krmné dávky.

Určitým problémem je modelování ekonomických podmínek, neboť prioritní postavení mají ekologické principy, avšak podnik musí dosahovat určité rentability výroby. Pro tyto úvahy nejsou k dispozici podkladové údaje o ekonomice provozu alternativně hospodařících rolníků. V modelu je jako kritérium optimality použita minimalizace nákladů na výrobu. Nalezení vhodného kritéria optimalizace je problémem, který lze řešit např. vícekriteriálním přístupem s využitím vektorové optimalizace.

Uvedený model je v současné době zkoušen na Školním zemědělském podniku Lány VŠZ v Praze, kde na hospodářství Požáry je ve spolupráci s Institutem pro ekologické zemědělství ve Švédsku zaváděno alternativní zemědělství.

ekologické (alternativní) zemědělství; optimalizační ekologický model; ekonomické cíle; kritérium optimality; linearita; statičnost; deterministický charakter; aktivity; omezující podmínky

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