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Research Report

Decision making models for sustainable development

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DECISION MAKING MODELS FOR SUSTAINABLE DEVELOPMENT

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Abstract. Economic growth is frequently considered to be in conflict with sustainable development and environmental quality. With increasingly stringent environmental regulations, there is a growing need for efficient production planning models that take into account the trade-off between return and environmental costs and therefore reduce the penalties paid for overcoming the pollution levels. This research report surveys partially the current state of the literature in operations research approaches to sustainable development. A special attention is paid to the application of portfolio theory and to loss function theory to sustainable development models. Our research has been focusing in the area of crop planning.

Keywords: multiple objective programming, production planning, environmental constraints, crop planning, portfolio theory, loss function theory

1. INTRODUCTION

Economic growth is frequently considered to be in conflict with sustainable development and environmental quality. In the last decades environmental considerations are increasingly playing an important part in our lives. Research activity directed toward environmental issues in production management has gained a great interest since the early 1990s. With increasingly stringent environmental regulations, there is a growing need for efficient production planning models that take into account the trade-off between return and environmental costs and therefore reduce the penalties paid for overcoming the pollution levels.

This research report surveys partially the current state of the literature in operations research approaches to crop planning. A special attention is paid to the application of portfolio theory and

to loss function theory to production planning models with environmental constraints. Several multiobjective programming models for agricultural production are formulated. A binary multiobjective model for crop planning under uncertainty in the presence of production quotas is presented. It uses loss functions and several target production quotas. Starting from the multiple objective programming model, one formulates several single objective models. We analyze losses associated to the optimal production plans that try to comply to the target production quotas versus various parameters of the average loss minimization model.

2. DECISION FOR SUSTAINABLE DEVELOPMENT

Sustainable development is essentially a process of change that allows current human needs to be satisfied, without compromising the possibilities of future generations (WCED, 1987). It is achieved through the use and conservation of the natural resource base and the maintenance and expansion of the diversity of social, technological, and productive options (Winograd, 1995).
Decision-making, in the development context, involves the design of a strategy, the definition of policies, and the execution of actions. Assessment and performance indicators must be used because decisions cannot be taken without information. The decision making process therefore involves a series of commonly used data, statistics and economic, social and environmental indicators. Decision making, just like development, is a dynamic process and is carried out at different levels of society, taking into account different cultural, social, economic, institutional, political, and environmental aspects. Therefore each stage of the decision-making cycle requires and uses different types of information.
The first stage of decision making involves identifying problems and risks, and creating an awareness about them, to be able to diagnose, based on assessment indicators, the state of the society, the economy, and the environment. Problems can then be monitored to provide information that will improve the decisions taken regarding actions on specific issues. Once the problems have been identified, then policies, strategies, and actions, based on multi-sectorial integration, should be formulated. Environmental and development problems obey multiple factors and have diverse consequences, and can be approached differently in political, economic, social, and cultural terms. By seeking equilibrium between existing and potential options, predictions can be made and a series of objectives and goals established to develop standards that can be used as reference values for implementing defined policies, strategies, and actions. The effectiveness and impact of adopted policies, strategies, and actions should also be evaluated. The fulfillment of objectives or goals and the progress made due to the measures that have been taken, also need to be evaluated in order to tailor actions and strategies, and guarantee the participation of all stakeholders. Objectives and goals should be evaluated periodically on the basis of the circumstances, evolution, and perceptions of problems. In addition to assessment indicators, performance indicators should also be defined for all stages of the decision making process.

3. APPLICATION OF FINANCIAL PORTFOLIO THEORY TO SUSTAINABLE DEVELOPMENT

An important mathematical instrument which was successfully applied to modeling the problems from the domain of sustainable development is portfolio theory. The above mentioned theory was developed as a result of the research in the domain of financial management. Its aim is the elaboration of a quantitative analysis of how investors can diversify their portfolio in order to minimize risk and maximize returns. The theory was introduced in 1952 by University of Chicago economics student Harry Markowitz, who published his doctoral thesis, "Portfolio Selection" in the Journal of Finance, Markowitz [14]. There exist many applications of portfolio theory to domains that do not imply finance.
Some of the applications belong to the domain of sustainable development.
Applications of financial portfolio theory to sustainable development include research on: crop planning models, aquaculture planning models, biodiversity planning models, forestry planning models, energy planning models, investment planning models in the presence of climate change.
A list of some references on the applications of portfolio theory to sustainable development is presented below: agriculture Blandon [3], Blank [5], Romero [46], [47], Radulescu [32]-[34]. [36], [40], [43], [44], sire selection Schneeberger [50], forestry Blandon [3], [4], Hanewinkel [13], Kaakyire [16], Knoke [19]-[21], biodiversity Figge [9], Koellner and Schmitz [22], energy Bazilian and Roques [1], sustainable production planning Radulescu [31], [35], [37]-[39], [41] etc.

Application of portfolio theory to agriculture
Computer-based decision support systems (DSSs) have a well-established tradition within crop planning in agriculture. The DSS for crop planning range from simple accounting-based systems to systems based on complex deterministic or stochastic models.
Romanian agriculture, which was for a long time considered a traditional, slow moving economic activity strongly dependent on subsidies and public support, is now a sector affected by many political changes and social pressures derived from environmental concerns and trade liberalizations requirements. Furthermore, the sector dynamics has dramatically increased due to technological innovations, rising world demand for food and raw materials and the new uses of traditional crops as energy sources. One of the most important decisions faced by farmers is the selection of crops they want to grow. Prospective growers must know how to use risk management strategies in order to select the crops that best suit their needs. One of the most popular approaches to managing risk is to reduce risk exposure through diversification. The uncertainty from the agriculture problems is modeled with the help of probability theory. Many of the practical problems that occur in agriculture are stochastic programming problems with multiple objectives. In practice, in the process of mathematical modeling, one cannot take into account all the factors that have an impact to agricultural production. The number of such factors is large and the growth of their number determines the rapid growth of the complexity of the models. An important mathematical instrument which was successfully applied to modeling the problems from agriculture was portfolio theory. The above mentioned theory was developed as a result of

the research in the domain of financial management. The application of portfolio theory for finding an optimal allocation of agricultural land is popular in the literature. The first application of the portfolio theory to crop planning goes back to Freund [6]. In Hardaker [7], Hazell and Norton [8], [9] and Blank [5] were presented or applied various variants of portfolio theory to the land allocation decisions.
In Collender [5], Romero [46], [47], were studied several models for resources allocation in agriculture that are taking into account specific risks. For other references regarding applications of portfolio theory to agriculture see Radulescu [32]-[34]. [36], [40], [43], [44].

Application of financial portfolio theory to fishery management and aquaculture planning

Application of financial portfolio theory to fishery management and aquaculture planning is a subject of great interest. The application of portfolio theory for finding an optimal harvesting portfolio is popular in the literature. Managing fish stocks in terms of a portfolio of financial assets is likely to significantly increase benefits for society relative to single species approaches. Fishery portfolio selection models for fishery management were formulated and analyzed in Hatch and Atwood [14], Sanchirico [49], Sethi [51]. In Sanchirico [49] the authors adapt financial portfolio theory as a method for ecosystem based fishery management that accounts for species interdependencies, uncertainty, and sustainability constraints. They illustrate their method with routinely collected data available from the Chesapeake Bay and demonstrate the gains from taking into account variances and covariances of gross fishing revenues in setting species total allowable catches. The Sanchirico's model from [49] was developed later in Radulescu [42]. In Larkin [24] the authors embed a portfolio decision framework into a multiperiod bioeconomic model in order to quantify the risk-benefit tradeoffs of alternative strategies. They develop alternative sets of processed seafood products for managing the risks that occur as a result of harvests from commercial fish stocks. The model is used to generate an efficient portfolio frontier to estimate possible rent dissipation from status quo management. Frontiers are also generated for seafood processors and brokers. The authors discuss implications for the different industry agents. Drawing the analogy between managing risky assets and managing multispecies fisheries is a relatively new idea, even though the foundation for this idea is neither new to ecology nor economics.

4 A MINIMUM FINANCIAL RISK MODEL FOR CROP PLANNING

In the following is formulated a 0-1 integer programming model for crop planning in agriculture. The model takes into account weather risks and market risks. Input data include historical data on land productivities for various crops and soil types.
Consider a farm which has an agricultural land divided into several plots $P_1, P_2, ..., P_m$. We consider that if a plot is cultivated then it is cultivated with the same crop. Also we consider that the soil quality of a plot is homogeneous.
Denote by S_j the area of the plot P_j, j=1, 2,..., m. We consider that the farmer have to choose a crop plan from n crops $C_1, C_2, ..., C_n$, that is to make an allocation of crops to plots.

Consider the probability space (Ω, K, P). Denote $I=\{1,2,...,n\}, J=\{1,2,...,m\}$. For every $i\in I$, $j\in J$ we define the random variables $c_{ij}:\Omega\to\mathbf{R}_+$ and $b_i:\Omega\to\mathbf{R}_+$. $c_{ij}(\cdot)$ are called the plot productivity functions and b_i are called the market price functions. $c_{ij}(\cdot)$ is the quantity of crop C_i that can be produced on an area of one hectare of plot P_j and b_i is the market price for a quantity of one kg of crop C_i. For every $i\in I$, $j\in J$, denote by:

- a_{ij} the cost for cultivating one ha of the plot P_j with crop C_i
- c_{ij} - the plot productivity coefficient, that is the quantity of crop C_i obtained from an area of one hectare of plot P_j.
- x_{ij} - the decision variable that takes the value 1 if the crop C_i is cultivated on plot P_j and takes value zero if the crop C_i is not cultivated on the plot P_j.
- $[M_1, M_2]$ the range for the sum of money available for investment
- Q_i the lower bound for the yield of crop C_i necessary to be obtained (contractual levels)

The yield of crop C_i is equal to $\sum_{j=1}^{m} c_{ij}(\cdot)S_j x_{ij}$, $i\in I$. The cultivation cost when the land allocation $\mathbf{x}=(x_{ij})$ of crops to plots is applied is equal to $\sum_{i=1}^{n}\sum_{j=1}^{m} a_{ij}S_j x_{ij}$.

The constraints $\sum_{i=1}^{n} x_{ij}\le 1$, $j\in J$ show that every plot is cultivated with at most one crop. The return (respectively the expected return) obtained when the decision matrix $\mathbf{x}$ is used is equal to:

$\psi(\cdot,\mathbf{x})=\sum_{i=1}^{n}\sum_{j=1}^{m} b_i c_{ij} S_j x_{ij}$ (respectively)

$E[\psi(\cdot,\mathbf{x})]=\sum_{i=1}^{n}\sum_{j=1}^{m} E(b_i c_{ij})S_j x_{ij}$.

For every $i,\alpha\in I$, $j,\beta\in J$, denote $\rho_{ij\alpha\beta}=E[b_i c_{ij} b_\alpha c_{\alpha\beta}]-E[b_i c_{ij}]\cdot E[b_\alpha c_{\alpha\beta}]$.

Then the variance of the return is equal to $\mathrm{Var}(\psi(\cdot,\mathbf{x}))=\sum_{i=1}^{n}\sum_{j=1}^{m}\sum_{\alpha=1}^{n}\sum_{\beta=1}^{m}\rho_{ij\alpha\beta}x_{ij}x_{\alpha\beta}S_j S_\beta$. The variance of the return has the meaning of financial risk.

In the frame of this problem the farmer tries to find an optimal allocation of crops to plots that minimize the financial risk taking into account that the expected return is greater than a given level *W*.

$$\begin{cases} \min(\mathrm{Var}(\psi(\cdot,\mathbf{x}))) \\ \sum_{j=1}^{m} E(c_{ij}) S_j x_{ij} \geq Q_i, i \in I \\ \sum_{i=1}^{n}\sum_{j=1}^{m} E(b_i c_{ij}) S_j x_{ij} - \sum_{i=1}^{n}\sum_{j=1}^{m} a_{ij} S_j x_{ij} \geq W \\ M_1 \leq \sum_{i=1}^{n}\sum_{j=1}^{m} a_{ij} S_j x_{ij} \leq M_2 \\ \sum_{i=1}^{n} x_{ij} \leq 1, \text{for every } j \in J, \\ x_{ij} \in \{0,1\}, i \in I,\ j \in J \end{cases}$$

An important problem in the decision process of the choice of a crop allocation to plots is the existence of some indicators that will guide the farmer in the selection of the parameters of the problem: M_1, M_2 and W. These indicators can be computed by solving several binary programming problems.

Denote by $M_1^{\min}$ (respectively by $M_2^{\max}$) the optimal value of the following two binary programming problems:

$$\begin{cases} \min\left(\sum_{i=1}^{n}\sum_{j=1}^{m} a_{ij} S_j x_{ij}\right) \\ \sum_{j=1}^{m} E(c_{ij}) S_j x_{ij} \geq Q_i, i \in I \\ \sum_{i=1}^{n} x_{ij} \leq 1, \text{for every } j \in J, \\ x_{ij} \in \{0,1\}, i \in I,\ j \in J \end{cases}$$

and

$$\begin{cases} \max\left(\sum_{i=1}^{n}\sum_{j=1}^{m} a_{ij} S_j x_{ij}\right) \\ \sum_{j=1}^{m} E(c_{ij}) S_j x_{ij} \geq Q_i, i \in I \\ \sum_{i=1}^{n} x_{ij} \leq 1, \text{for every } j \in J, \\ x_{ij} \in \{0,1\}, i \in I,\ j \in J \end{cases}$$

The farmer has to choose the parameters M_1, M_2 in the range $\left[M_1^{\min}, M_2^{\max}\right]$. After that the farmer has to determine the range from where he has to choose the parameter W. Denote by W_1 (respectively by W_2) the optimal value of the following binary programming problems:

$$\begin{cases} \min\left(\sum_{i=1}^{n}\sum_{j=1}^{\infty} E(b_j c_{ij}) S_j x_{ij} - \sum_{i=1}^{n}\sum_{j=1}^{\infty} a_{ij} S_j x_{ij}\right) \\ \sum_{j=1}^{\infty} E(c_{ij}) S_j x_{ij} \geq Q_i, i \in I \\ M_1 \leq \sum_{i=1}^{n}\sum_{j=1}^{\infty} a_{ij} S_j x_{ij} \leq M_2 \\ \sum_{i=1}^{n} x_{ij} \leq 1, \text{ for every } j \in J, \\ x_{ij} \in \{0,1\}, i \in I, j \in J \end{cases}$$

and

$$\begin{cases} \max\left(\sum_{i=1}^{n}\sum_{j=1}^{\infty} E(b_j c_{ij}) S_j x_{ij} - \sum_{i=1}^{n}\sum_{j=1}^{\infty} a_{ij} S_j x_{ij}\right) \\ \sum_{j=1}^{\infty} E(c_{ij}) S_j x_{ij} \geq Q_i, i \in I \\ M_1 \leq \sum_{i=1}^{n}\sum_{j=1}^{\infty} a_{ij} S_j x_{ij} \leq M_2 \\ \sum_{i=1}^{n} x_{ij} \leq 1, \text{ for every } j \in J, \\ x_{ij} \in \{0,1\}, i \in I, j \in J \end{cases}$$

The farmer has to choose the parameter W in the interval $[W_1, W_2]$.

5. A DECISION SUPPORT TOOL FOR CROP PLANNING UNDER RISK

Based on the crop planning model presented above, a decision support software tool was developed. Its name is MINRISK. The crop planning model in MINRISK was solved with the solver MINLP from GAMS. MINRISK is composed from the following modules: “User Interface”, “Input data”, “Model resolution”, and “Sensitivity analysis”. The input data collection is built and validated in the module “Input data” following a set of rules. The module “model resolution” facilitates the model building, transition of the model to the GAMS solver MINLP, solves the model and returns the results back. In order to make the validation of the user parameters the module solves several mathematical programming problems. As a result, ranges of variation for the user parameters are determined. For example, for the determination of the range of variation of the user parameter W, the module solves two linear programming problems. The results are visualized and saved according to the user demand. The module “sensitivity analysis” allows by the variation of the user parameter W, the computation of the efficient frontier of the crop planning model.

6. FORMULATION OF A MULTIOBJECTIVE MODEL FOR CROP PLANNING IN AGRICULTURE BASED ON PORTFOLIO THEORY AND LOSS FUNCTION THEORY

The last decades witnessed an increasing interest in sustainable agriculture and a rapid progress in reaching it. Several environmental regulations were introduced in the Common Agricultural Policy (CAP) of European Union. As a result several agricultural subsidies were introduced and various development programs were implemented. The production quotas were introduced in the Common Agricultural Policy of the European Union in order to protect the environment, to prevent the exhaustion of agricultural resources and to ensure farmers a stable income. In the present paragraph we shall develop several crop planning models based on loss functions. These kinds of models are used when optimal production plans are desired and target production quotas are involved. Agricultural production under or above the quota targets receive penalizations, therefore it is discouraged.

In the next subparagraph we present a brief introduction in the theory of loss functions.

In the third subparagraph is formulated a 0-1 multiple objective programming model for crop planning under uncertainty in the presence of production quotas. It uses loss functions and several target production quotas. Starting from the multiple objective programming model, one formulates several single objective models. We analyze losses associated to the optimal production plans that try to comply to the target production quotas versus various parameters of the average loss minimization model.

6.1. Loss functions

The notion of loss function occurs in various domains as: the theory of statistical decisions, the actuarial theory, learning theory, pattern recognition, time series, quality theory. The domains where loss functions apply include: economics, finance, engineering, health, agriculture and environment.

In statistics a loss function represents the loss (cost in money or loss in utility in some other sense) associated with an estimate being "wrong" (different from either a desired or a true value) as a function of a measure of the degree of wrongness (generally the difference between the estimated value and the true or desired value.)

The notion of loss function is complementary to the notion of utility function which suggests the benefit and satisfaction. If u is an utility function then $k - u$ is the loss, where k is an arbitrary constant.

There is a great demand from the applicative domains for the development of theory of various classes of loss functions. An important class of loss functions is the class of unimodal loss functions. Some interesting studies about this class of functions may be found in (Zbaganu, 2006).

Applications of loss functions to investments can be found in (Kulkarni and Prybutok, 2004). Some books that represent good references for the theory of loss functions are (Berger, 1993), (Clements and Hendry 1998), (Cameron and Trivedi, 2005), (Granger C.W.J. and Paul Newbold, 1977), (DeGroot, 2005).

In the literature there are several approaches about loss functions. A general definition of loss functions is presented in the following.

Let (E,E) be a measurable space. A loss function on E is any measurable function $L : E^2 \to [0,\infty]$ with the property that $L(x,x) = 0$. We shall often denote $L_x(y)$ the mapping $y \to L(x,y)$. Let (Ω,K, P) be a probability space and $X : \Omega \to E$ be a random variable.

Let $h:E \to [0,\infty]$ be defined by $h_X(y) = E[L(X,y)]$, $y \in E$. The optimal predictor of X defined by L is an element $A_L(X) \in E$ with the property that $h_X(A_L(X)) \le h_X(y)$ for every $y \in E$

The following notation is usually: $A_L(X) = \operatorname{argmin} h_X$.

Under some hypotheses the number exists and it is unique (see (Zbaganu, 2006)).

Another approach on loss functions, which we shall use in our paper is the following.

Consider a family of random variables $X(\lambda):\Omega \to \mathbf{R}$, $\lambda \in \Lambda$, and a loss function $L:\mathbf{R}^2 \to \mathbf{R}_+$.

We propose to solve the problem:

$$\min\{E[L(X(\lambda), y)]: \lambda \in \Lambda\}$$

Examples of loss functions:

1. Quadratic loss function: $L_a(s,t) = a(t-s)^2$, $s,t \in \mathbf{R}$.
2. Absolute loss function $L_a(s,t) = a|t-s|$, $s,t \in \mathbf{R}$
3. Linlin loss function

$$L_{a,b}(s,t) = \begin{cases} a|s-t| \text{ if } s \le t \\ b|s-t| \text{ if } t \ge s \end{cases}$$

One can easily see that

$$L_{a,b}(s,t) = \frac{a+b}{2}|s-t| + \frac{b-a}{2}(s-t)$$

Here a,b are nonnegative parameters.

4. LINEX loss function

$$L_a(s,t) = \exp(a(s-t)) - a(s-t) - 1.$$

Here where a is a known parameter and $a \neq 0$.

Exhaustive motivations to use the LINEX loss function are presented in (Varian, 1974) and (Zellner, 1986). These examples shows that loss function influences the choice of the predictor. Each predictor has its own interpretation. Quadratic loss function penalizes large deviations of the predictor t from "true" value of the parameter. Absolute loss is more tolerant to large deviations.

6.2. Crop planning models for sustainable agriculture

In the following is formulated a 0-1 integer programming model with multiple objectives for crop planning in agriculture. The model takes into account weather risks and market risks. Input data include historical land productivities data for various crops and soil types. Some special cases of the model are discussed.

Consider a farm which has an agricultural land divided into several plots. Let $P_1, P_2, ..., P_m$ be the plots from the farm's land. We consider that if a plot is cultivated then it is cultivated with the same crop. Also we consider that the soil quality of a plot is homogeneous. Denote by S_j the area of the plot P_j, j=1, 2,..., m. We consider that the farmer have a contract for delivery some fixed quantities of various crops. These quantities can be considered crop target quotas. Agricultural production under these quotas may be subject to contractual penalizations. Agricultural production over the quota targets can be sold by the farmers on the free market (local markets or international markets). Unfortunately on the free market does not exist minimum prices.

We consider that the farmer have to choose a crop plan from n crops $C_1, C_2, ..., C_n$, that is to make an allocation of crops to plots.

Consider the probability space $(\Omega, \mathsf{K}, \mathsf{P})$. Denote $I = \{1,2,...,n\}, J = \{1,2,...,m\}$. For every $i \in I$, $j \in J$ we define the random variables $c_{ij} : \Omega \to \mathbf{R}_+$ and $b_i : \Omega \to \mathbf{R}_+$. c_{ij} are called the plot productivity functions and b_i are called the market price functions. c_{ij} represents the quantity of crop C_i that can be produced on an area of one hectare of plot P_j and b_i represent the market price for a quantity of one tone of crop C_i. For every $i \in I$, $j \in J$, denote by:

- a_{ij} the cultivation cost for one ha of the plot P_j with crop C_i
- x_{ij} - the decision variable that takes the value 1 if the crop C_i is cultivated on plot P_j and takes value zero if the crop C_i is not cultivated on the plot P_j.
- $[M_1, M_2]$ the range for the sum of money available for investment
- Q_{1i} the target quota for crop C_i (contractual level)
- Q_{2i} the inferior bound for the expected yield of crop C_i necessary to be obtained

The yield of crop C_i obtained from the plot P_j when the land allocation decisions are given by the matrix $\mathbf{x} = (x_{ij})$, is

equal to $x_{ij} S_j c_{ij}$. The yield of crop C_i is equal to $\sum_{j=1}^{m} c_{ij}(\cdot) S_j x_{ij}$, $i \in I$. The cultivation cost when the land allocation $\mathbf{x} = (x_{ij})$ of crops to plots is applied is equal to $\sum_{i=1}^{n} \sum_{j=1}^{m} a_{ij} S_j x_{ij}$. The restrictions $\sum_{i=1}^{n} x_{ij} \le 1$, $j \in J$ show that every plot is cultivated with at most one crop. The return

(respectively the expected return) obtained when the decision matrix **x** is used is equal to $\psi(\cdot,\mathbf{x})=\sum_{i=1}^{n}\sum_{j=1}^{m} b_i c_{ij} S_j x_{ij}$ (respectively) $\sum_{i=1}^{n}\sum_{j=1}^{m} E(b_i c_{ij}) S_j x_{ij}$.

For every $i,\alpha \in I$, $j,\beta \in J$, denote $\rho_{ij\alpha\beta}=E[b_i c_{ij} b_\alpha c_{\alpha\beta}]-E[b_i c_{ij}]\cdot E[b_\alpha c_{\alpha\beta}]$.

Then the variance of the return is equal to $\mathrm{Var}(\psi(\cdot,\mathbf{x}))=\sum_{i=1}^{n}\sum_{j=1}^{m}\sum_{\alpha=1}^{n}\sum_{\beta=1}^{m}\rho_{ij\alpha\beta} x_{ij} x_{\alpha\beta} S_j S_\beta$. The variance of the return has the meaning of financial risk.

The farmer intends to obtain optimal production plans that

- minimize the expected loss of the allocation
- minimize the financial risk
- maximize the expected return.

Let L_i , $i\in I$ be loss functions associated to crops. The overall expected loss for the allocation $\mathbf{x}=(x_{ij})$ is equal to

$$E\left[L_i\left(\sum_{j=1}^{m} c_{ij}(\cdot) S_j x_{ij}, Q_{1i}\right)\right].$$

According to the above requirements the multiobjective programming model for the crop planning is the following:

$$\begin{cases} \min\left\{\sum_{i=1}^{n} E\left[L_i\left(\sum_{j=1}^{m} c_{ij}(\cdot) S_j x_{ij}, Q_{1i}\right)\right]\right\} \\ \min(\mathrm{Var}(\psi(\cdot,\mathbf{x}))) \\ \max\left(\sum_{i=1}^{n}\sum_{j=1}^{m} E(b_i c_{ij}) S_j x_{ij} - \sum_{i=1}^{n}\sum_{j=1}^{m} a_{ij} S_j x_{ij}\right) \\ \sum_{j=1}^{m} E(c_{ij}) S_j x_{ij} \ge Q_{2i},\ i\in I \\ M_1 \le \sum_{i=1}^{n}\sum_{j=1}^{m} a_{ij} S_j x_{ij} \le M_2 \\ \sum_{i=1}^{n} x_{ij} \le 1, \text{ for every } j\in J, \\ x_{ij}\in\{0,1\},\ i\in I,\ j\in J \end{cases}$$

Starting from the above multiobjective programming problem we formulate four single objective problems.

The first one is the expected loss minimization model:

$$
\begin{cases}
\min\left\{\sum_{i=1}^{n} E\left[L_i\left(\sum_{j=1}^{m} c_{ij}(\cdot) S_j x_{ij}, Q_{1i}\right)\right]\right\} \\
\mathrm{Var}(\psi(\cdot, \mathbf{x})) \le \tau \\
\sum_{i=1}^{n}\sum_{j=1}^{m} E(b_i c_{ij}) S_j x_{ij} - \sum_{i=1}^{n}\sum_{j=1}^{m} a_{ij} S_j x_{ij} \ge W \\
\sum_{j=1}^{m} E(c_{ij}) S_j x_{ij} \ge Q_{2i}, i \in I \\
M_1 \le \sum_{i=1}^{n}\sum_{j=1}^{m} a_{ij} S_j x_{ij} \le M_2 \\
\sum_{i=1}^{n} x_{ij} \le 1, \text{for every } j \in J, \\
x_{ij} \in \{0,1\}, i \in I,\ j \in J
\end{cases}
$$

In the frame of this model the farmer wants to find an optimal allocation $\mathbf{x} = (x_{ij})$ that minimize the overall expected loss in the presence of the following restrictions:

- the financial risk is smaller than a given level τ
- the expected net return is greater than a given level W
- the expected quantities of crops are greater than some given levels Q_{2i}, $i \in I$
- the total tillage cost is in the range $[M_1, M_2]$.

The user parameters of the model are: τ, W, M_1, M_2 and the parameters of the loss functions.

Denote by V the set of all allocations $\mathbf{x} = (x_{ij})$ that satisfy the following restrictions:

$$
\begin{cases}
\sum_{j=1}^{m} E(c_{ij}) S_j x_{ij} \ge Q_{2i}, i \in I \\
M_1 \le \sum_{i=1}^{n}\sum_{j=1}^{m} a_{ij} S_j x_{ij} \le M_2 \\
\sum_{i=1}^{n} x_{ij} \le 1, \text{for every } j \in J, \\
x_{ij} \in \{0,1\}, i \in I,\ j \in J
\end{cases}
$$

The expected return maximization model is formulated as follows:

$$\begin{cases} \max\left\{\sum_{i=1}^{n}\sum_{j=1}^{m} E(b_i c_{\bar{ij}})S_j x_{\bar{ij}} - \sum_{i=1}^{n}\sum_{j=1}^{m} a_{\bar{ij}} S_j x_{ij}\right\} \\ \sum_{i=1}^{n} E\left[L_i\left(\sum_{j=1}^{m} c_{\bar{ij}}(\cdot)S_j x_{ij}, Q_{1i}\right)\right] \le \lambda \\ \mathrm{Var}(\psi(\cdot, \mathbf{x})) \le \tau \\ \mathbf{x} \in V \end{cases}$$

The formulation of the financial risk minimization model is the following:

$$\begin{cases} \min\{\mathrm{Var}(\psi(\cdot, \mathbf{x}))\} \\ \sum_{i=1}^{n} E\left[L_i\left(\sum_{j=1}^{m} c_{\bar{ij}}(\cdot)S_j x_{ij}, Q_{1i}\right)\right] \le \lambda \\ \sum_{i=1}^{n}\sum_{j=1}^{m} E(b_i c_{\bar{ij}})S_j x_{ij} - \sum_{i=1}^{n}\sum_{j=1}^{m} a_{\bar{ij}} S_j x_{ij} \ge W \\ \mathbf{x} \in V \end{cases}$$

The loss-return-risk tradeoff model is formulated as follows:

$$\begin{cases} \min\{\alpha \mathrm{Var}(\psi(\cdot, \mathbf{x})) + \beta L(\mathbf{x}) - \gamma R(\mathbf{x})\} \\ \sum_{i=1}^{n} E\left[L_i\left(\sum_{j=1}^{m} c_{\bar{ij}}(\cdot)S_j x_{ij}, Q_{1i}\right)\right] \le \lambda \\ \sum_{i=1}^{n}\sum_{j=1}^{m} E(b_i c_{\bar{ij}})S_j x_{ij} - \sum_{i=1}^{n}\sum_{j=1}^{m} a_{\bar{ij}} S_j x_{ij} \ge W \\ \mathbf{x} \in V \end{cases}$$

where α, β, γ are nonnegative coefficients.

We denoted $L(\mathbf{x}) = \sum_{i=1}^{n} E\left[L_i\left(\sum_{j=1}^{m} c_{ij}(\cdot)S_j x_{ij}, Q_{1i}\right)\right]$, $R(\mathbf{x}) = \sum_{i=1}^{n}\sum_{j=1}^{m} E(b_i c_{ij})S_j x_{\bar{ij}} - \sum_{i=1}^{n}\sum_{j=1}^{m} a_{ij} S_j x_{\bar{ij}}$.

7. CONCLUSION

The purpose of the present paper is to present various strategies based on portfolio theory and loss function theory that are intended for prevention of pollution and the exhaustion of natural resources.

The paper presents several crop planning models under uncertainty that take into account both the economic and environmental problems. The crop planning problems are multiobjective programming problems. The models presented are based on portfolio theory. Here the portfolios are represented by sustainable crop plans. The sixth paragraph contains a multiobjective model for crop planning in the presence of crop target quotas. Crop quotas can be motivated by contractual levels or by environmental constraints. They contribute to the prevention of the exhaustion of agricultural resources. The multiobjective model for crop planning is based on

portfolio theory and on loss function theory. Here portfolios are represented by crop plans. In all above mentioned models ranges of the user parameters are determined. This facilitates the integration of our optimization models in environmental management decision support systems.

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