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Review Article

CROP MANAGEMENT BY LINEAR PROGRAMMING. A LITERATURE REVIEW

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ABSTRACT

Mathematical Programming is used to determine the best or optimal solution to a problem that requires a decision or set of decisions regarding the use of existing limited resources to achieve an objective. Linear Programming is a widely used technique mathematical modeling to determine the optimal allocation of resources between competing requirements. In the present study, a review of the use of linear programming for crop management is made and its methodology is analyzed.

Keywords: crop management, linear programming, restrictions, objective.

INTRODUCTION

Each producer must make the right decisions about the products he will produce through the crop or crops he has, the method to be used, the final quantities he will produce and the time period in which he will produce the products. In order to make these decisions, he must take into account both the physical and financial constraints of his exploitation as well as the relative uncertainty about the period ahead of him in order to implement his decision. Uncertainty is affected by the forecasts of crop yields, costs, prices of each product produced as well as the requirements of the sectors of factors of production in relation to their available quantities. Producers tend to rely on their experiences, comparisons with neighboring crops and their intuition to make specific decisions [Martika-Vakirtzi,2008] Linear Programming (LP) methodology is the most popular model in business research and management science. Its success in decision-making problems in both public and private companies as well as in organizations is due to the achievements of economists and mathematicians as well as the development of technology and information technology. It is now widely accepted that most applications of business research models to management problems are solved by linear programming [Jensen, 1983]. Linear programming is used to deliver the optimal or minimum solution to a constrained problem. It deals with the design of the activities of a system in order to produce the best result, that is, the one that among all possible alternatives achieves the predetermined purpose in the best way [Gass, 2003]. Linear programming applies solutions to theoretical computing as well. It is used to model combinational problems which at first glance do not seem to be related to linear programming [Cococcioni *et al.,* 2018]. The first mathematical formulation of the problem as well as a process for solving it, the Simplex algorithm, is due to G.B. Dantzig in 1947 [Dantzig and Glynn, 1990].

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LITERATURE REVIEW

A bibliography was searched in 3 databases (agEcon, google scholar, scopus) [15,16,17] with many different results. The phrases "crop distribution", "linear programming", and "linear programming in agriculture" were searched in all 3 databases where they gave us the following results (table 1). It is observed that most of the results are from the phrase "linear programming", so we conclude that linear programming method is applied in sectors other than agriculture.

Databases	CropDistribution	LinearProgramming	LinearProgramming in agriculture
scopus	35.933	137.837	938
agEcon	1.261	792	173
googlescholar	3.240.000	3.460.000	279.000

Table 1: Results from databases

Below are uses of linear programming in the agricultural sector for crop management as well as for other reasons. Four cases are reported from data obtained from scientific works (from their abstracts). In agriculture, the production structure of farms can be highly diversified to reduce risk and uncertainty related to unsealing the products. To determine the optimal structure of crops, different methods which take into account the income and expenditure of crops per hectare are used. As a result, the area of each crop is identified, so that, in combining them to derive maximum profit level. In their study, Andreea, I. R., & Adrian, T. R (2012) use linear programming method for optimizing profit, investigating whether, after applying the econometric model, the profit increased or not. The results show that profit rose to 143% and costs reduced to 81% [Andreea and Adrian, 2012]. Amidst continual global population growth, land degradation and climate change, consumers are becoming more aware of the environmental impact of their diet. People in cities are also looking to mitigate the risk of disruption to their food supply through adoption of urban agriculture (UA). It is not at all clear, however, what impact UA will ultimately have on urban food security. The informal nature of many UA enterprises makes quantification difficult, and some projections of cities “feeding themselves" appear to simply reflect untested optimism. Ward, J. D. *et al.,* 2016, demonstrate in their study, the novel use of Linear Programming (LP) to explore different dietary preferences (high meat intake versus vegetarian), and to determine the feasibility of urban agriculture (UA) making a substantial contribution to food security. The model quantifies the maximum potential impact of locally-grown produce in terms of either reducing cost or maximising the dietary contribution. Results show that LP can be used effectively to explore optimal cropping on urban land, based on the amount of available land per capita. A key finding of this feasibility study is that the contribution of UA to realistic diets—while limited—need not be trivial. In our case study of Northern Adelaide, Australia, it appears that 10–15% of dietary protein could be produced in a typical suburban backyard, with or without chicken meat, along with savings of around AU$1 per person per day. Both the nature of the optimal UA crop regime and its impact are shown to depend on the dietary context, especially the level of meat consumption [Ward *et al.,* 2014]. Tiotsop, L. F. *et al.,* in 2020, used linear programming in their study for precision agriculture. In precision agriculture more and more robots are being used to perform tasks that may include some farming activities, such as pruning, inspection or spraying, assigned to the robot as a result of a previous analysis activity or autonomously identified by the machine itself. In this sensitive scenario, reporting difficult situations to a decision maker, e.g., a human operator or some sophisticated software tools that cannot be integrated with the robot, could be useful to perform the correct action that the machine has to execute. Unfortunately, this key aspect is still neglected in current literature that focuses, instead, on fully automated operations by robots. Moreover, it is necessary to consider that in rural areas it often happens that successful data communication can only be achieved in certain locations in the field. Two alternative analytical formulations of the problem are presented, an integer linear programming model (ILP) and a mixed integer linear programming model. A branch and bound algorithm that is guaranteed to find the global minimum cost solution in terms of navigation time is proposed. Simulation results show that the algorithm proposed, performs about 20 to 30 times faster with respect to commercial linear programming solvers using any of the two analytical models proposed. Moreover, we also propose further improvements to reduce computational time while maintaining solution optimality. Finally, some insight into the development of future heuristics is given by analyzing the speed of convergence towards the optimal solution [Tiotsop *et al.,* 2020] Otoo, J. *et al.,* in 2015 use linear programming in their study for crop management. The main purpose of their study was to present a formulated Linear Programming (LP) Model for 16 selected small scale farmers from 32 operational areas of Fanteakwa District in the Eastern Region of Ghana. The study considered ten (10) crops namely garden eggs, water melon, cabbage, onion, tomato, cucumber, okra, pepper, cocoa (nursery) and plantain. The formulated LP Model for this study assumed profit maximizing behavior, a single-period planning and a certain environment. The formulated LP Model suggested no production of sole crop enterprises like cabbage, onion, cocoa (nursery), pepper (grown on raised bed), pepper and garden egg (grown on raised bed + irrigation). The model also prescribed no production for crop mixtures like garden egg/okra and cabbage/cucumber/pepper. The formulated LP Model prescribed production of 1 acre of garden egg, 3 acres of watermelon, 4 acres of tomato, 2 acres of cucumber, 1 acre of plantain, 2 acres of garden egg (irrigation), 1 acre of okra/garden egg/pepper and 1 acre of pepper/garden egg. Comparison of results obtained by using existing farming plan and the LP Model indicate that results obtained from the LP Model were significant improvements of the existing farming plan. The LP Model saved 0.2% and 0.6% of available capital and labor requirement respectively. A 16.25% significant increment of the net returns was obtained by the LP Model. This was as result of net returns increasing from GH¢77,848.00 to GH¢88,177.00. These results suggest the essence of application of formulated mathematical models like the LP Model to planning and management of limited resources [Otoo *et al.,* 2015].

MATERIALS AND METHOD

Linear Programming is a useful tool and in case someone manages to transfer their problem to the field of linear programming they will have a set of tools that will give them the strongest and best solution to their problem, as well as a list of data to perform case analysis parameters of the problem [Goldfarb and Todd, 1989].

For the formulation of the linear model, there are the following steps for analysis [Andreea and Adrian, 2012]:

The problem variables: These are the structural elements of the problem that the analyst can influence. They are also referred to in the literature as control variables or decision variables. A typical example is the daily harvest of products in a rural area by a food industry that prepares its production line for standardization. There are several variables that exist in such a problem. Some of them are the various agricultural species that are collected such as:

- X1: the quantity (kg) of fruit and vegetables prepared
- X2: the quantity (kg) of vegetables produced
- X3: the quantity (kg) of vines produced
- X4:…

(It is customary to use the symbol X to represent a variable and with an index i = 1,2,3,… .. we achieve the distinction between them).

Objective: Each decision variable changes / affects the outcome of the objective. We can set the goal of maximizing profit, the optimal use of raw materials, the use of labor, the production of products under environmental restrictions, etc. We are looking to identify the values of the control variables that will give us the optimal performance criterion that we define at this stage of modeling. In the previous case (the example above) we could define as a goal of the industry that exploits the rural area the division of crops in the area based on the optimization of economic performance under environmental constraints and therefore look for a way of expressing crop sharing as a function of decision variables estimating its contribution individually.

Restrictions: It is probably the most important factor influencing the final result. They can be physical restrictions (soil qualities), economic (capital), institutional (contracts), subjective (personal preferences).

The linear programming model can be presented as follows [Messner *et al.,* 1996; Fytilis K., 2022]:

$$\sum_{j=1}^{n} c_j x_j = z = \max ormin orz = \sum c_j xj + \sum \left(-Cjx_j\right)$$

Restrictions:

$$\sum_{i=1}^{k} a_{ij} x_j \leq b_i$$

$$x_j \geq 0$$

Where:

j = branches of production (if n are the possible branches then j = 1 to n)
Xj = acres of industry j
Cj = gross profit of the industry
Z= maximum total gross profit or minimum cost

i = available factor (if k is the number of factors then i = 1 as k)
aij = quantity of available rate used by the industry
bi = the quantity of the factor i. Bi is the limitations

The function means that the goal is to find a production plan that gives us the largest possible total gross profit Z, without ignoring the restrictions (quantities of fixed rates and non-negativity). As mentioned above the restrictions contribute significantly to the final result. The most commonly used restrictions are 4: land use, capital, labor and non negativity [Martika-Vakirtzi, 2008]. So, the final function can take the following form:

$$Z = \sum_{i=1}^{n} NiXi\, , i = 1,2,3, \dots \dots \dots \dots . . n$$

Variable description:

Z = The total net returns from all the crops
n = The number of crops
Ni = The net return
Xi = The area from crops

Restrictions:

Land use:

$$\sum_{i=1}^{n} \boldsymbol{Xi \leq TA}$$

Where:

TA = Total land area under cultivation of crops

Capital

$$\sum_{i=1}^{n} \boldsymbol{CiXi \leq TC}$$

Where:

Ci = The capital requirement for each crop
TC = The total capital requirement for all crops

Labor

$$\sum_{i=1}^{n} \boldsymbol{LiXi \leq TL}$$

Where:

Li = The labor requirement for each crop
TL = The total requirement for all the crops

Non - negativity

$$Xi \geq 1,2,3,4 \dots \dots . . n.$$

DISCUSSION

As observed, linear programming is a dynamic and useful tool that is applied in all production sectors. Its gradual evolution has helped science and technology to make significant strides in crop management (and not just in the primary sector). The future evolution of linear programming can be an important tool for resource management due to climate change [Henseler *et al.,* 2009]. Thus we conclude that linear programming is essential for proper management.

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