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NOTE

INCORPORATING MULTIPLE OBJECTIVES IN FARM PLANNING: APPLICATION OF GOAL PROGRAMMING TECHNIQUE

J. TORKAMANI[1]

Department of Agricultural Economics, College of Agriculture, Shiraz University, Shiraz, I.R. Iran.

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ABSTRACT

Decision makers usually engage in the optimization of multiple goals rather than a single objective. So, management problems may need to be analyzed in the multi-objective framework. Multiple criteria decision making models have been proposed to solve multiple objective problems. This paper shows how weighted goal programming technique can be applied to farm planning problems. Data used in the current study come from a sample of 68 farmers, who were selected by a two-stage cluster sampling method, from the Sarvestan plain, Fars province. Cluster analysis method was used in order to classify sample farms into homogenous groups. Then, conventional linear programming and weighted goal programming models of the representative farms were compared with their existing farm plans. The modeling results indicated that goal programming is a more powerful and flexible technique, as compared to conventional linear programming, to analyze farm planning problems.

Key words: Lexicographic goal programming, Multi-objective problems, Weighted goal programming.

1. Associate Professor.

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دخالت دادن هدف های چند گانه در برنامه ریزی مزرعه: کاربرد روش برنامه ریزی آرمانی

جواد ترکمانی

دانشیار بخش اقتصاد کشاورزی، دانشکده کشاورزی دانشگاه شیراز، شیراز، جمهوری اسلامی ایران.

چکیده

تصمیم گیران معمولا" با بهینه کردن چندین هدف روبرو هستند. بنابراین، مسائل مدیریتی را می توان در یک چارچوبه چند هدفی بررسی کرد. روش های تصمیم گیری چند معیاری برای حل مسائل دارای هدف های چند گانه پیشنهاد شده است. در این مقاله، نحوه استفاده از روش برنامه ریزی آرمانی وزن دار در حل مسائل برنامه ریزی مزرعه نشان داده شده است. داده ها ی مورد استفاد در این مطالعه، با روش نمونه گیری دو مرحله ای خوشه ای، از نمونه ای شامل ۶۸ نفر از زارعان دشت سروستان در استان فارس جمع آوری شد. از روش تحلیل خوشه ای برای تقسیم بندی زارعان عضو نمونه در گروه های همگن استفاده شد. سپس، مدل های برنامه ریزی خطی سنتی و برنامه ریزی آرمانی وزن دار مزرعه های نماینده با برنامه کنونی آن ها مقایسه شد. نتایج نشان داد که برنامه ریزی آرمانی، در مقایسه با برنامه ریزی خطی سنتی، از توانایی و انعطاف پذیری بیشتری برخوردار است.

INTRODUCTION

The problem of efficiently allocating resources faces all organizations in one or more forms. The techniques of mathematical programming provide a powerful set of approaches for tackling this type of problem. A variety of problems of management decision making can be formulated and solved as linear programming (LP) problems.

In agriculture, most of the conventional LP models are involved in the optimization of a single objective (usually gross margin) subject to the limited resources (13, 15) but decision makers usually engage in the pursuit of multiple conflict objectives rather than a single minimization or maximization objective (3, 4). This seems to be the case either at farm level or sector level, where competition occurs over utilization of scarce factors of production. A farmer may want to maximize gross margin as well as cash income, reduce fixed cost, increase leisure, secure food supplies for the family, avoid risk, etc. So, the planning programs need to be analyzed in a multi-objective framework.

Several approaches, including goal programming (GP), multi-objective programming (MOP) and compromise programming (CP) have been introduced to deal with multiple objective decision making in business (3, 14, 19). Of these techniques, GP, minimizing the weighted deviations of multiple objectives from the desired levels of goals, is a powerful and flexible technique for modeling modern decision making problems. It can be solved by any conventional LP software but provides a simultaneous solution to a complex system of competing objectives (17).

In the farm planning context, GP and its variants, such as lexicographic goal programming (LGP) and weighted goal programming (WGP), have been considered by many researchers to be a very powerful and flexible technique for making decision to most resource allocation problems for optimal production of seasonal crops (6). Romero and Rehman (17) have provided an expository analysis and assessment of GP as one of the most widely-used techniques for dealing with multi-criteria decision making in farm planning. According to Price (16), GP corresponds well with the usual conceptions of the manager's decision making process including goal setting and goal ranking. Romero and Rehman (18) emphasize the inadequacy of the LP technique in agricultural decision making and suggest MCDM methods, including the GP technique, for farm planning and the analysis of managerial decisions in agriculture. The use of GP and its variants in farm planning have been surveyed by Zanakis and Gupta (20) and Glen (5). Their assessment of the results of the GP method in different operational researches and management systems support the adequacy of this technique in farm planning. Application of GP to Iranian agriculture in order to analyze farm plans has not been reported yet.

In the light of above discussion, the main purpose of this paper is to show how the GP technique may be applied to practical farm planning. The next section describes the conceptual structure of GP techniques. The farm management planning models of LP and GP then are presented. In the final section, results of an empirical study based on cross sectional data on a sample of farmers in the Sarvestan plain, Fars province, are presented and discussed.

METHODOLOGY

GP, originally introduced by Charnes and Cooper (3) and further developed by Ijiri (11) and others, is very similar to the traditional LP concept, and can be solved using modified simplex method. Also, all of the data required for LP are essential for GP. However, GP can be employed in decision problems with a single objective and multiple subgoals, as well as, in cases having multiple goals and subgoals. Goals are included in the structural constraints of the LP model in the form of equalities. The right hand side (RHS) elements of these equations are targets to which the decision maker aspires. However, this target or aspiration level may or may not be achieved.

An aspiration level (T_i) is a desirable level of achievement for any related goal. So, GP, compared with LP, requires more variables and some changes in the basic equations. In other words the original matrix of technical coefficients of LP form part of the matrix of GP.

The structure and functions of the GP model are very similar to LP. An LP model can be converted to GP by adding deviation variables and imposing appropriate changes in mathematical forms of the constraints. Deviation variables are specific elements of the GP process that record the positive (p_i) or negative (n_i) deviation of outcome from the predetermined target. In other words, p_i and n_i are, respectively, under-achievement and over- achievement of the i-th specific level for each goal. Consequently, in a GP model we shall refer only to objectives. These objectives may be the result of i) the desires of the decision maker, ii) limited resources and/or iii) any other restrictions either explicitly or implicitly placed on the choice of decision variables. Once all of the objective functions and associated RHS's are defined as a list of inequalities, they can be converted to equalities by adding positive and/or negative deviation variables (i.e., p_i and n_i, respectively) to their left hand sides. In general form, it can be presented as:

$$T_i = f_i (X) + n_i - p_i$$

where f_i (X) is the i-dimension objective function, X is an n-dimension vector of decision variables, and p_i and n_i are, respectively, the over-and under deviational variables for the i-th target.

The final step in model formulation is to establish the achievement or the objective function. The objective function in GP is to minimize the sum of appropriate deviational variables (i.e., p_i when the goal is minimized and n_i when it is maximized) for each goal. It expresses the level of achievement of each objective. The achievement function therefore takes the following form:

$$\text{Minimize } \Sigma_i\, p_i + n_i \qquad \text{for all I's}$$

In practice, for any objective row in the matrix, two columns are included namely p_j and n_j. The value of elements a_{ij} in the intersection of row R_i and columns p_j and n_j for i=j equal +1 and -1, respectively. The values of the rest of the elements in the columns p_j and n_j are zero. Then, the minimization process can be accomplished by introducing pre-emptive weights as in lexicographic GP (LGP) or by attaching non pre-emptive weights to goals as in weighted GP (WGP). In other words, goal satisfaction occurs in a stated sequential order, goal A, then goal B and then goal C in LGP. However, in WGP, goal satisfaction may be traded off using weights on deviations from target levels (13, 17).

Application of LGP to management problems can result in a solution that satisfies several goals of decision makers. However, it has some inherent weakness which limits its applicability in farm management. It is not possible to assign equal priorities to the goals with different natures. The ordering of different goals implies absolute preference for a goal that is given a higher priority relative to a lower priority goal, whereas the decision maker may be equally concerned about the two goals. For these reasons, in this study, WGP approach was used.

As a logical way of unification of different units of measurements a ratio of decision maker's proposed weights over the aspiration levels can be attached to the deviation variables. In this case all the goals can be considered in a composite objective function that minimizes the sum of all deviations among the goals and their aspiration levels. Thus, instead of ordering the goals in a discrete pre-emptive manner, it is possible to weight the deviations continuously according to the relative importance of each goal to the decision maker. The formula for creating the weighted composite objective function can be presented as:

$$\text{Minimize } \Sigma_i W_i [(p_i + n_i)/(T_i)100] \qquad \text{for all I's}$$

where W_i is the weight assigned to i-th goal, and T_i is the aspiration level (i.e., the target) of the decision maker.

In the present study, the above procedure was applied to obtain the solution of the WGP. It considers all the goals simultaneously, and unlike LGP the solutions can be obtained in a single course of running the model, reducing the time of running the model without any decline in the accuracy of the results.

The farm-level data used in this study consisted of information on production for a sample farm in the Sarvestan plain, Fars province. The area receives around 300 mm of rainfall per year. Most of the precipitation occurs in January and the least in May. The overall climatic condition can be classified as semi-arid. Agriculture is the main activity in the region. Data were collected through a survey for the year 1998-1999. The major crops are wheat, barley, cotton, sugar beet and maize. Comprehensive information regarding farm size, access to farm inputs and credit, outputs, prices and costs was collected from a sample of 68 farmers who were selected by a two-stage cluster sampling method. Data were collected on each of the inputs and outputs by crops. They are recorded both in quantity and value terms.

Building a model for each individual farm is a time-consuming, expensive and inefficient practice. The alternative is to classify sample farms into homogeneous groups and construct one representative model for each group (9). In the current study, following Buckwell and Hazell (2) and Hazell and Norton (7), cluster analysis was used in order to classify the sample farms on the basis of farm size. According to these authors, this classification assigns farms with similar resource endowment proportions, in particular land-to-labor ratios, to the same group.

The cluster analysis divided the sample farms into two size classes: i.e., smaller than 10 ha (small farms) and 10 ha and larger (large farms). Then, following Buckwell and Hazell (2) and Hazell and Norton (7), the median farm was chosen as being representative after ranking the farms on the basis of their area. Once all of the basic data and technical information were available, LP models were constructed for both representative farms, and optimum farm plans for the representative farms were estimated using the computer program QSB^{+} to solve the LP model of the farm. Then, the original matrices of the LP models were used as the cores of GP models for the representative small and large farms. As Ignízio (10) stated, the basic LP model is essential for the purpose of designing a precise GP. The base line LP model can be stated as follows:

Maximize the objective function

$$Z = c'X$$

subject to

$$AX\ (\leq = \geq)\ b$$

and $$X \geq 0$$

where Z = objective function;

c = vector of activity net returns;

X = vector of levels of activities;

A = matrix of input-output coefficients; and

b = vector of resources and constraint levels.

The WGP problem may be presented as the following general form:

Minimize

$$\sum_i W_i [(p_i + n_i)/(T_i)100] \qquad \text{for all i's}$$

subject to

$$f_i (X) + n_i - p_i = T_i \qquad \text{for all i's}$$

$$AX (\leq = \geq) b$$

and $X \geq 0, \quad n_i, p_i \geq 0$ for all i's

where, W_i is the weight attached to the i-th goal, and the T_i is the target for the i-th objective, respectively.

In this study, based on field observations, discussion with local experts and previous studies, two goals were selected. These were to maximize total net return, and to minimize annual total variable cost. Then, according to the results of the LP solution and the subjective priorities of the representative farmer, appropriate targets and weights were selected for the above goals, respectively. The LP and WGP models of the representative farms were solved by using the computer programs QSB^+ and GAMS/MINOS (1), respectively.

RESULTS AND DISCUSSION

In the current study, the prediction ability of the LP model was assessed by forcing the program to produce the same crop activity levels as the real farm levels. Then, the solution values of its objective function and also the level of resource use were compared with the existing farm plan. This comparison suggested that the amount of hired labor in the model solution was higher than actually employed by the representative farms. Revising the labor periods by increasing their number to 14 and also providing proper linkages between labor hiring and selling and cash flows in different cash periods eliminated this problem. Also, the possibility of transferring cash from one period to the next was not considered in the initial model. This caused non-feasible solutions, particularly for the large representative farm, when the model was forced to produce the same crop activity levels as the real farm. To eliminate this problem, three cash balances (i.e., balances at three critical dates through the agricultural year) were specified and the initial working capital was included in the RHS of the first cash balance date. Following the adjustment, matrix structure and preliminary model output were again carefully reviewed and followed by other revisions of matrix as appropriate, until the model was finally judged to be satisfactory for its intended purpose.

Table 1 shows the results obtained from models of profit maximization and GP for the small representative farm. The corresponding existing farm plan is also presented in the same table. Comparison of the actual farm plan and the optimum allocation solution, selected by the LP model, suggests a potential of 983500 Rials increase in the objective function, showing an increase of about 11.42% in the total net return as compared to the existing farm plan. Aspiration levels of 10000000 and 3500000 Rials then were set, indicating the target levels of the total net return and annual total variable cost of the small representative farm, respectively. The detailed cropping pattern of the WGP model is also presented in Table 1, assuming that both goals are of equal importance for the manager. It is evident from Table 1 that, although the total net return of the WGP model is higher than those of the existing farm plan, it is lower than the LP model and target level of the small representative farm. The optimal deviational variable values for maximization of total net return (n_1 and p_1), and minimization of annual total variable cost (n_2 and p_2) are:

$n_1 = 815300$ $\quad$ $p_1 = 0$ for
$n_2 = 0$ $\quad$ $p_2 = 145000$

Table 1. Comparison of the results of the LP and WGP models with existing farm plan for the small representative farm†

	Activity levels						
	Barley (ha)	Cotton (ha)	Maize (ha)	Sugar beet (ha)	unflower (ha)	Wheat (ha)	TNR§ (1000 Rials)
EFP¶	2.50	0.50	0.00	1.00	0.00	3.50	8609.00
PMFP††	0.50	1.00	0.75	1.20	1.50	2.50	9592.50
WGPFP§§	1.80	0.70	0.50	1.20	0.45	2.85	9184.70

† The small representative farm has 7.5 ha of operated land.
§ TNR stands for total net return.
¶ EFP represents existing farm plan.
†† PMFP represents profit maximizing farm plan selected by LP model.
§§ WGPFP represents farm plan selected by WGP model.

The results indicated that neither total net return nor annual total variable cost reached the target levels. However, their values were improved as compared to those of the existing farm plan.

The complete results of LP and WGP models as well as the existing farm plan for the large representative farm are presented in Table 2, assuming that both goals are of equal importance for the manager. To obtain the solution of the WGP model, target levels of 25000000 and 7000000 Rials were set for the desired levels of the total net return and annual total variable cost of the large representative farm, respectively. The optimal deviational variable values are:

$n_1 = 4321500$ $p_1 = 0$ for
$n_2 = 0$ $p_2 = 0$

Table 2. Comparison of the results of the LP and WGP models with existing farm plan for the large representative farm†.

	Activity levels						
	Barley (ha)	Cotton (ha)	Maize (ha)	Sugar beet (ha)	Sunflower (ha)	Wheat (ha)	TNR§ (1000 Rials)
EFP¶	3.50	2.50	1.00	2.00	1.00	5.50	19284.20
PMFP††	1.50	3.50	2.00	1.90	3.50	3.00	21752.60
WGPFP§§	2.95	2.00	1.50	1.50	2.45	5.00	20678.50

† The large representative farm has 15.5 ha of operated land.

§ TNR stands for total net return.

¶ EFP represents existing farm plan.

†† PMFP represents profit maximizing farm plan selected by LP model.

§§ WGPFP represents farm plan selected by WGP model.

Thus, the first goal is under-achieved (i.e., the total net return did not reach the desired level). However, the second goal regarding the minimization of annual total variable cost is satisfied. As was discussed earlier, decision making problems may be analyzed in the multi-objective framework. This study, therefore, has attempted to show the application of WGP, in the Iranian agriculture. However, although the WGP model proved to be a successful and flexible approach, practical assessment of other MCDM approach will be appropriate. Also, it is noteworthy to remember that successful performance of any modeling procedure depends on the accuracy of the data.

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