Acta Ciencia Indica, Vol. XL M, No. 2, 165 (2014)

GOAL PROGRAMMING MODEL FOR DETERMINING OPTIMUM FERTILIZER COMBINATIONS

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RECEIVED : 2 January, 2014

In this paper various goal programming models were used to analyze optimum fertilizer combinations. Under this approach the fertilizer requirements, instead of being fixed values as in traditional linear programming, are considered targets, which may or may not be achieved. A penalty system coupled to the goal programming model makes the specified lower and upper levels of nutrients more flexible and realistic. A simple example is used to expound the model. Sensitivity analysis of the goals has been performed to obtain all possible solutions.

KEYWORDS: Goal Programming, Fertilizers, Sensitivity Analysis.

Introduction

Many plants need 16 elements for normal growth and completion of their life cycle. These elements are called the essential plant nutrients. Soil amendments containing the essential plant nutrients or having the effect of favourably changing the soil chemistry have been developed and used to enhance plant nutrition. Crop productivity measured in terms of responses to fertilizers can only be sustained if soil fertility levels are maintained to match with crops' need and in a proper proportion. Organic manure can be used in place of chemical fertilizer to avoid long-run negative effects of chemical fertilizer on the soil. However organic manure is usually required in large quantity to sustain crop production and may not be available to the small scale farmers, hence the need for inorganic fertilizers.

Nitrogen (N), Phosphorous (P) and Potassium (K) are referred to as primary or macronutrients. This is because they are required by the plant in large amounts relative to other nutrients and they are the nutrients most likely to be found limiting plant growth and development in the soil systems. The best way to select a fertilizer grade is by soil tested. The soil test report will recommend the fertilizer grade for use.

Most fertilizers are labeled with the nutrient content on the front of the package. All the fertilizers are labeled with three numbers (N-P-K) which are the percentage weight of the Nitrogen (N), Phosphorus Citrate (P_2O_5) and Potassium (K_2O) respectively. To calculate the kgs of nitrogen in a 50 kg bag of 10-10-10 fertilizer, multiply 50 by 0.10. Do the same for calculating the amounts of phosphate and potash. A 50 kg bag of 10-10-10 contains a total of

15 kgs of nutrients: 5 kgs nitrogen, 5 kgs phosphate and 5 kgs potash. The remaining weight is filler, usually sand or granular limestone.

A fertilizer is said to be complete or mixed fertilizer when it contains nitrogen, phosphorus and potassium (the primary nutrients). Some examples for complete fertilizers are 15-15-15,

17-17-17, 20-10-10. An incomplete fertilizer will be missing one or more of the major components. Some examples for incomplete fertilizers are 18-46-0 (Di Ammonium phosphate), 46-0-0 (Urea) etc. In complete fertilizers are blended to make complete fertilizers. As an example, if 100 pounds of 46-0-0 (urea) is combined with 100 pounds of 0-46-0 (concentrate super phosphate) and 100 pounds of 0-0-60 (muriate of potash), a fertilizer of grade 15-15-20 as a result.

Low commercial fertilizer use by smallholder farmers in developing regions of the world commonly constrains productivity. Many of these farmers do not have the financial capacity to purchase enough fertilizer to maximize net returns on their limited investment per hectare. High fertilizer costs and low commodity prices often reduce profit potential. Competing needs for money often take priority. Such farmers need high net returns on their investments to justify the application of fertilizers. Maximizing net returns requires the fertilizer investments focus on crop-nutrient with the highest marginal returns until the budgeted financial resources are exhausted.

Linear programming (LP) has been used from many years to determine the optimum fertilizer combination for a certain crop. Once the crop nutrient requirements are satisfied, it minimizes cost of the blend. However it is precisely the need to fulfill the restriction that none of the constraints on the nutrient levels may be violated under any circumstances, which makes LP too restrictive and unrealistic when used to optimize fertilizer combinations.

These kinds of over rigid specifications may exclude substantial economies in the fertilizer combination. In some cases, a possible decrease in the crop yield could be compensated for by a decrease in the cost of the applied fertilizer combination.

A goal programming (GP) model was used here to analyze the optimum fertilizer combination. Under GP, the nutrient requirements, instead of being fixed values, are considered targets that the farmer aspires to, although these may or may not achieve. The purpose of the objective function of the model is to minimize the weighted deviations between the target values and the actual amount of nutrients selected.

GP has proved to be very useful and promising tool in the field of decision making. Wheeler and Russel used goal programming in agriculture planning while Ghosh [2003] *et. al*. formulated a goal programming model of nutrient management for rice production in west Bengal. Hasan and Tabar dealt with decision making of multi objective resource allocation problems. Latinopoulos and Mylopoulos (2005) made use of goals programming for optimal allocation of land and water resources agriculture. Sharma *et. al*. (2007) used fuzzy goal programming for agriculture land allocation problems. Vivekananda *et. al*. (2009) used goal programming for the optimization of cropping pattern for a particular region, concentrating mainly on the factors like net return and proper utilization of surface and ground water in irrigated agriculture, Jafari *et al* (2008) formulated lexicographic goal programming model for rice farm. Mohamad (2011) developed a mathematical programming model for crop mix problem. Hassan *et al*. (2012) used preemptive goal programming model for multi-objective nutrient management problem by determining the optimum fertilizer combination for chilli plantation in Sungai Buloh Malaysia. Alireza Karbasi *et al*. (2012) discussed the goal programming for the optimal combinations of different kinds of fertilizers for rice cultivation.

In the paper of Shaik Md. *et al*. (2010), a multi-objective forest management process employing mathematical programming and the analytical hierarchy process had been developed for systematically incorporating public input. Hassan, N. and S. Sahrin (2012) developed a Mathematical Model of Nutrient Management For Pineapple Cultivation in Malaysia. Dinesh K. *et al*. (2013) used goal programming model for the Management decision-making sugarcane fertilizer mix problems. Goal programming was also recently applied, with some success, to the live stock ration formulation problem, which is closely related to the fertilizer combination problem. The purpose of this paper is to introduce GP as an alternative to LP in the taking of the problem. GP has some advantage over the LP.

DATA OF THE PROBLEM

Let us consider a simplified example, where a farmer wishes to determine the amounts of two liquid fertilizers mixtures *A* and *B*, in order to minimize his total fertilizer costs.

Suppose the cost and composition of the primary nutrients for the two mixtures are as follows:

Table 1

	Fertilizer mixture *A* (19-19-19)	**Fertilizer mixture *B* (15-15-15)**
Cost (Rs /ton)	22000	21000
Nitrogen (kg of N/ton)	190	150
Phosphorus (kg of P_2O_5/ton)	190	150
Potassium (kg of K_2O/ton)	190	150

2.1. GENERAL LINEAR PROGRAMMING

The general goal programming model may be expressed as

Optimize (Maximize or minimize) $Z = \sum_{j=1}^{n} C_j x_j$

s.t $\sum_{j=1}^{n} a_{ij} x_j (\le, =, \ge) b_i \quad (i = 1, 2, \ldots m), \quad x_j \ge 0 \quad (j = 1, 2, \ldots n)$

(i) $x_1, x_2, \ldots\ldots x_n$ are choice variables or decision variables.

(ii) $c_1, c_2, \ldots\ldots c_n$ are called cost or profit coefficients or per unit contribution to the objective function of the corresponding decision variables.

(iii) a_{ij} $(i = 1, 2, \ldots m\,;\ j = 1, 2, \ldots n)$ are called structural coefficients.

(iv) $b_1, b_2, \ldots\ldots b_m$ represents requirement (or) availability of m constraints each constraint may take only one of the three possible forms.

(v) $x_j \ge 0$ $(j = 1, 2, \ldots n)$ simply implies that the x_j's must be non negative.

2.1.1 FERTILIZER COMBINATION AS LINEAR PROGRAMMING MODEL

The fertilizer requirements per hectare are : 80 kg nitrogen, 50 kg phosphorous (P_2O_5) and 60 kg potassium (K_2O). The least-cost combination can then be obtained by solving the following LP problem:

$$\text{Min } Z = 22000\, X_1 + 210000\, X_2$$
$$\text{Subject to } 190X_1 + 150X_2 \geq 80$$
$$190X_1 + 150X_2 \geq 50$$
$$190X_1 + 150X_2 \geq 70$$
$$X_1, X_2 \geq 0 \qquad \ldots(1)$$

where, X_1 and X_2 are the amounts of fertilizer mixtures A and B to be used.

2.2 RESULT AND ANALYSIS

After solving problem, the solution $X_1 = 0.4211$ and $X_2 = 0$ is found. In other words, the least-cost solution consists in using 0.4211 tons of mixture A. The optimum cost associated with this policy is Rs. 9263. The surplus variable for the nitrogen nutrient is almost zero, thus making this constraint binding surplus variables for phosphorus and potassium are 30 and 20 kg, respectively.

The solution of the LP problem given by (1) above is the mathematical optimum, but to which is it also the economic optimum? Most probably a relaxation in the only binding restraints allows a reduction in cost without seriously impairing crop yield.

However, as we are dealing with a very simplified example, the effect that certain relations with the nitrogen requirements would have on costs could be found within the LP model. The transformation curve between the cost and amount of nitrogen in the soil could be obtained by a parametric variation of the right-hand side of the constraint. Thus, in a more realistic case where the possible fertilizer mixtures and where the micronutrients as well as the primary nutrients requirements are considered, the parametric option could not be used successful. Another problem with LP may arise when the crops are sensitive to an excess of the nutrients and/or micronutrients. When an excess of the nutrient can affect yield in negative way, it is wise to set an upper as well as a lower limit for each nutrient. However, in many cases, this approach can generate over-constrained problems with empty feasible sets. For instance, if an upper limit of 75 kg potassium were set in our simplified example, there would be no solution which could satisfy every single constraint. There are also other cases in which an upper limit does not produce infeasibility but makes the optimum solution more and more expensive as the size of the feasible set becomes smaller. These problems can be avoided if GP and not LP is used.

GENERAL GOAL PROGRAMMING PROBLEM

The GP approach as an extension of LP was first introduced into the literature by Charnes and Cooper in [1961] for solving the unsolvable LP problems. They thought that whether goals are attainable or not, an objective may then be stated in which optimization gives a result which comes as close as possible to the indicated goals. These deviations from the goals will exit in unsolvable LP problems like infeasible LP problem, Charnes and Cooper illustrated how that deviation could be minimized by placing deviation variables directly in the objective function of the model. This allows multiple conflicting goals to be expressed in the model that will permit a solution to be found.

Charnes and Cooper presented GP model as

$$\text{Minimize } Z = \sum_{i \in m} d_i^{+} + d_i^{-}$$

$$s.t \sum_{j=1}^{n} a_{ij} x_j - d_i^{+} + d_i^{-} = b_i \quad \text{for } i = 1, 2, \ldots m$$

$$d_i^{+}, d_i^{-}, x_j \geq 0 \quad \text{for } i = 1, 2, \ldots m \; ; \; j = 1, 2, \ldots n$$

where d_i^{+}, d_i^{-} are the positive and negative deviations from the target values.

a_{ij} 's are technological coefficients represent per unit usage by x_j.

Later Y. Ijiri (1965) studied the techniques of goal programming based on the concepts of cooper & Charnes. He presented the definition of preemptive priority factors to treat multiple goals according to their importance, assigning weights to goals at the same priority level. The ideas of weighting or ranking goals are two very different concepts, leads to two different types of GP models.

Charnes and Cooper (1977) stated **weighted GP Model (Non Preemptive GP)** as

$$\text{Minimize } Z = \sum_{i \in m} w_i^{+} d_i^{+} + w_i^{-} d_i^{-}$$

$$s.t \sum_{j=1}^{n} a_{ij} x_j - d_i^{+} + d_i^{-} = b_i \quad \text{for } i = 1, 2, \ldots m$$

$$d_i^{+}, d_i^{-}, x_j \geq 0 \quad \text{for } i = 1, 2, \ldots m \; ; \; j = 1, 2, \ldots n$$

where w_i^{+}, w_i^{-} are non negative constraints representing the relative weights to be assigned to the respective positive and negative deviations. The relative weights may be any real number, where the greater the weight the greater the assigned importance to minimize the respective deviation variable to which the relative weight is attached. This is non preemptive model that seeks to minimize the total weighted deviations from all goals stated in the model.

Based on Ijiri (1965) idea of combining preemptive priorities and weighting. Charnes and Cooper suggested the **Preemptive Goal Programming** Model as

$$\text{Minimize } Z = \sum_{i \in m} p_i (w_i^{+} d_i^{+} + w_i^{-} d_i^{-})$$

$$s.t \sum_{j=1}^{n} a_{ij} x_j - d_i^{+} + d_i^{-} = b_i \quad \text{for } i = 1, 2, \ldots m$$

$$d_i^{+}, d_i^{-}, x_j \geq 0 \quad \text{for } i = 1, 2, \ldots m \; ; \; j = 1, 2, \ldots n$$

where p_i is priority level of i^{th} goal. The objective of GP is to achieve set of goals according to their priorities subject to the given set of system constraints. Thus GP involves a repetitive process by which the most important goal (p_1) is considered first. This is followed by an attempt to achieve the second goal (p_2) to the possible extent subject to the first goal achieved. This process continues until all goals have been considered in the priority ranking specified by management.

Charnes and Cooper pointed out the fact that, the above GP model allow us to move completely away from weighting deviation variables towards an absolute priority structure, where each goal is assigned a separate priority leads to **Lexicographic GP model.** This model has no weights, only a preemptive ranking for each of the goals, and is stated as

$$\text{Minimize } Z = \sum_{i \in m} p_i (d_i^{+} + d_i^{-})$$

$$s.t \sum_{j=1}^{n} a_{ij} x_j - d_i^{+} + d_i^{-} = b_i \quad \text{for } i = 1, 2, \ldots m$$

$$d_i^{+}, d_i^{-}, x_j \geq 0 \quad \text{for } i = 1, 2, \ldots m \,;\; j = 1, 2, \ldots n$$

Other types of GP models are also suggested, among all in the above said models more research publications has occurs.

3.1. FERTILIZER COMBINATION AS GP MODEL

The GP approach was first introduced into the literature by Charnes and Cooper in [1961]. Further methodology has been extended by Ijiri, Lee and others. Comprehensive books on the subject have been written by Lee, Ignizio, and Romero etc. Agriculture planning problems cannot deal with a single goal of maximizing output or profits. These problems involve a number of goals such as maximizing total crop production and overall profit, minimizing expenditure on labor, water requirements and other cost related elements. These goals are conflicting in nature. It is a difficult task to maximize or minimize all goals simultaneously. Certain goals out of these can only be achieved at the expense of others, making it difficult for the decision maker to come up with an optimum plan. Goal programming (GP) is an effective and useful tool for dealing with problems having multiple and conflicting goals and for obtaining an optimum Solution which comes closest to meeting the stated goals given the constraints of the problem. Goal programming is capable of handling effectively the problem involving multiple goals. GP model and its variants have been applied to solve large-scale multi-criteria decision–making problems.

GP minimizes the deviations between the desired target levels and the actual results by transforming the inequalities of the model into equalities. This is done by adding the positive and negative deviational variables which permits either the under or over achievement of each goal. Amongst the different possible approaches capable of minimizing the deviational variables, we chose weighted goal programming (WGP) based on relative properties to solve our fertilizer-combination problem. The sum of all the deviations between the goals and their corresponding targets is minimized by the objective function of a WGP model. The deviations are then weighted according to the relative importance of each goal.

The LP model given by (1) plus the constraints referring to the upper limit of 75kg K_2O can be transformed into the following goals:

$$(G_1)\ 190X_1 + 150X_2 + d_1^{-} - d_1^{+} = 80$$

$$(G_2)\ 190X_1 + 150X_2 + d_2^{-} - d_2^{+} = 50$$

$$(G_3)\ 190X_1 + 150X_2 + d_3^{-} - d_3^{+} = 60$$

$$(G_4)\ 190X_1 + 150X_2 + d_4^{-} - d_4^{+} = 75$$

$$(G_5)\ 22000X_1 + 21000X_2 + d_5^{-} - d_5^{+} = 9263 \qquad \ldots (2)$$

The target for the goal cost was set at 9263 Rs/ha in order to offer our farmer a fertilizer combination with a cost as close as possible to the one he was offered with LP [*i.e.* the least-cost solution].

The negative deviational variables (d_i^-) measure the under-achievement of each goal with respect to its target. For example, d_1^- = 30 kg means that the nitrogen goal has fallen short by 30 kg. In other words, the actual supply of nitrogen added to the soil has been 50 kg. The positive deviational variables (d_i^+) play just the opposite role. That is, each one measures the amount by which the goal has surpassed its own target. For example, d_5^+ = 1000 means that the cost goal is over its target by 1000 or that the actual cost of the fertilizer combination is Rs.10263.

In order to obtain the desired levels of goals G_1, G_2 and G_3, the negative deviational variables d_1^-, d_2^- and d_3^- must be minimized. However, if the desired levels of goals G_4 and G_5 are to be found, then it is necessary to minimize the positive deviational variables d_4^+ and d_5^+. Hence, to achieve these goals, the following sum of the deviational variables should be minimized:

$$w_1 d_1^- + w_2 d_2^- + w_3 d_3^- + w_4 d_4^+ + w_5 d_5^+ \qquad \textbf{... (3)}$$

Subject to equations (2). In other words, (3) represents the objective function of the WGP model and (2) its goal constraints. The weights (w_i) represent the relative importance given by the farmer to the achievement of the various goals.

An anomaly underlying the structure of the objective function (3) should be commented upon and corrected. Thus, as the target value of goal G_5 is 9263, whilst the target values of the other goals range between 50 and 80, the solution provided by the model would be biased to the achievement of goal G_5. This problem, which is very common in GP, can be easily overcome by using percentage deviations from targets instead of absolute deviations. Therefore, the objective function (3) can be transformed into:

Minimize:

$$w_1 x \frac{d_1^-}{80} x \frac{100}{1} + w_2 x \frac{d_2^-}{50} x \frac{100}{1} + w_3 x \frac{d_3^-}{60} x \frac{100}{1} + w_4 x \frac{d_4^+}{75} x \frac{100}{1} + w_5 x \frac{d_5^+}{9263} x \frac{100}{1} \qquad \text{... (4)}$$

In short, a WGP formulation of our fertilizer-combination problem is given by (4) as the objective function and (2) as the set of goal constraints in the model.

RESULTS AND ANALYSIS

The solution will be obtained by using the QSB$^+$ computer software is as follows:

Table 2

	x_1	x_2	d_1^-	d_1^+	d_2^-	d_2^+	d_3^-	d_3^+	d_4^-	d_4^+	d_5^-	d_5^+

$w_1 = w_2 = w_3 = w_4 = w_5$	0	0.4	20	0	0	10	0	0	15	0	863	0
If weight of N is increased by 20% and original weights to others are same	0.4210	0	0.0014	0	0	29.9	0	19.9	0	4.978	0	0
If weight of N is increased by 15% and original weights to others are same	0	0.441	13.836	0	0	16.164	0	6.164	8.84	0	0	0

In the case of $w_1 = w_2 = w_3 = w_4 = w_5$, goals are equally important for the farmer, the WGP solution is obtained by applying 400 kg/ha fertilizer mixture *B*. With this solution, all the goals, except the nitrogen one, are achieved for their targets. There is a negative deviation of 20 kg for the nitrogen goal, i.e. an actual supply of nitrogen to the soil of 60 kg. The actual cost of the combination is 8400 Rs/ha, or Rs 863 cheaper than the least-cost solution when the upper limit for potassium was not included.

A sensitivity analysis with the weights (w_i) attached to the deviational variables can provide the decision-maker with worthwhile information. For instance, if greater importance is given to the nitrogen goal than to the other goals, and then a higher weight should be attached to the deviational variable d_1^-, keeping the original weights for the other ones. Thus, if the weight w_1 attached to d_1^- is increased by 20%, the following new solution is obtained by applying 421 kg/ha of fertilizer A. In this solution, the actual cost of the blend is Rs. 9263, the achievement of Nitrogen is 79.99 (almost fully achieved), and the achievement of phosphorus goal is 79.9 (d_2^+ = 29.9) and achievement for the potassium goal is 79.9 kg [d_3^+ = 19.9 kg]. Here all the goals expect G_4 are achieved. If the weight w_1 is increased by 15%, then the solution is obtained by 441 kg/ha of fertilizer *B*. In the solution, the actual cost is Rs. 9263, and all the goals except the Nitrogen one are achieved. The actual level of achievement for Nitrogen is 66.16 kg (d_1^- = 13.836).

If we use Lexicographic goal programming for the constraints in (2) the results for the various priorities of the deviation variables, the following tables shows the sensitive analysis of the cost of combinations of fertilizers. The solutions are obtained by applying QSB+ Software.

Table 3

Priorities	x_1	x_2	d_1^-	d_1^+	d_2^-	d_2^+	d_3^-	d_3^+	d_4^-	d_4^+	d_5^-	d_5^+

$p_1 : d_1^-, p_2 : d_4^+$ $p_3 : d_4^+, p_4 : d_2^-, p_5 : d_3^-$	0.421	0	0	0	0	30	0	20	0	5	0	0.157
$p_1 : d_5^+, p_2 : d_4^+$ $p_3 : d_1^-, p_4 : (d_2^- + d_3^-)$	0.268	0.159	5	0	0	25	0	15	0	0	0	0
$p_1 : d_5^+, p_2 : d_4^+$ $p_3 : d_3^+, p_4 : d_2^+, p_5 : d_3^+$	0	0.333	30	0	0	0	10	0	25	0	2263	0
$p_1 : d_5^+, p_2 : d_4^+$ $p_3 : d_1^-, p_4 : d_2^+, p_5 : d_3^+)$	0.268	0.159	5	0	0	25	0	15	0	0	0	0

Which of these solutions the farmer chooses will depend on the preference he gives to each one of these goals. In other words, it will depend on the trade-off values between the goals considered. If trade-offs between the different goals are provided, it is possible to obtain with this type of sensitivity analysis an array of information. This information is what will enable the farmer to choose the fertilizer combination that best suits his needs. However, we would like to point out that the WGP and Lexicographic GP approaches used in this section is not the only variants in GP capable of minimizing the deviational variables. There are other GP approaches, where the maximum deviations between the goals and their targets are minimized, which can be used for this purpose.

Summary and Conclusions

This paper presents various types of Goal programming models to determine optimum fertilizer combinations, as an alternative to the traditional techniques based on LP. A set of data have been used to test the effectiveness and efficiency of the proposed model. Although it is not possible to obtain a guaranteed optimal solution, we demonstrate that a satisfactory solution can be achieved. Moreover, with the fertilizer combination, the current cost of fertilizer used can be reduced. The flexibility of the model can be done by adjusting the goal priorities with respect to the importance of each objective. This model can be modified by inserting other goals in the problem. The most important advantages of GP can be summarized as follows:

(a) In GP, instead of considering the nutrient requirements as fixed targets- which is unrealistic–they are treated as goals which may or may not be achieved. This flexibility avoids infeasibilities and increases the realism of the model, thus providing the farmer with information difficult to get with LP.

(b) With GP, it is possible to deal with the relative importance of the nutrient requirements for crop yield if priorities and weights are attached to the deviation variables of the objective function of the model.

(c) In general, the approach proposed permits the farmer to establish trade-offs between the different nutrient requirements and cost of the combination.

This model can assist the agriculture scientists to guide the farmers, about the best fertilizer combinations by which cost of fertilizer can be reduced.

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