Goal Programming Formulation in Nutrient Management for Chilli Plantation in Sungai Buloh, Malaysia

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ABSTRACT

This paper presents a preemptive goal programming model for multi-objective nutrient management problem by determining the optimum fertilizer combination for chilli plantation in Sungai Buloh Malaysia. Application of nutrients to the soil is commonly done by using fertilizers. A fertilizer is said to be a complete or mixed fertilizer when it contains nitrogen, phosphorus and potassium (N-P-K). A set of data have been used to test the effectiveness and efficiency of the proposed model. Results of the model indicate that all objectives have been achieved. Moreover with the fertilizer combination, the current cost of fertilizer used for chilli plantation can be reduced. The flexibility of the model can be done by adjusting the goal priorities with respect to the importance of each objective.

Key words: Goal programming; nutrient management; fertilizer combination.

Introduction

Chilli is a very popular and common spice found in green or dried ripe fruit of pungent form. It is an indispensable spice in every house in tropical countries. An understanding of soil chemical properties is important because of their effect on nutrient availability to plants. These properties may usually be favorably altered with the use of lime and/or fertilizer materials. Many plants need 18 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 favorably 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 [12]. Parr et al. [14] suggested that organic manure should be used in place of chemical fertilizer to avoid long-term 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 as noted by Nyathi and Campbell [13], hence the need for inorganic fertilizer. The positive effect of the application of inorganic fertilizers on crop yields and yield improvement have been reported by Carsky and Iwuator [1].

Nitrogen (N), phosphorus (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 soil systems. The fertilizer guaranteed analysis or grade, stated on the bag, refers to how much of an element is in the material (the guaranteed minimum quantity present) based on percentage by weight. All fertilizers are labeled with three numbers which give the percentage by weight of total nitrogen (N), citrate-soluble phosphorus (expressed as P2O5) and water-soluble potassium (expressed as K2O), respectively. Often, to simplify matters, these numbers are said to represent nitrogen, phosphorus and potassium (N, P, and K).

A fertilizer is said to be a complete or mixed fertilizer when it contains nitrogen, phosphorus and potassium (the primary nutrients). Examples of commonly used complete fertilizers are 6-12-12, 10-
10-10, 15-15-15 and 20-10-10. An incomplete fertilizer will be missing one or more of the major components. Examples of incomplete fertilizers are: 34-0-0 (ammonium nitrate), 46-0-0 (urea), 18-46-0 (diammonium phosphate), 0-46-0 (triple super phosphate) and 0-0-60 (muriate of potash). Incomplete fertilizers are blended to make complete fertilizers. As an example, if 100 pounds of 46-0-0 (urea) were combined with 100 pounds of 0-46-0 (concentrated super phosphate) and 100 pounds of 0-0-60 (muriate of potash), a fertilizer grade of 15-15-20 would result. When these quantities are combined, each quantity is diluted by the other two materials by one-third, provided each fertilizer material contributed equal weight to the blend. The fertilizer ratio indicates the proportion of N, P2O5 and K2O contained in the fertilizer. The specific fertilizer ratio needed depends on the soil nutrient level. For example, a 1-1-1 ratio (10-10-10 or 15-15-15) is widely used at planting time when both phosphorus and potassium are in short supply (soil tests low or medium). When soils test high or very high in phosphorus and potassium, a 1-0-0 ratio (34-0-0 or 46-0-0) may be a more appropriate choice for use at or near planting.

Model Formulation:

According to Ignizio [11], Goal Programming (GP) was introduced by Charnes and Cooper in the early 1960s to solve multi-objective mathematical programming model. Charnes and Cooper [2] reviewed goal programming as a tool for multi objective analysis. Wheeler and Russell [18] used goal programming in agricultural planning while Ghosh et al. [4] formulated a goal programming model of nutrient management for rice production in West Bengal. Hassan et al. [9, 10] and Hassan and Tabar [8] dealt with decision making of multiobjective resource allocation problems. Schniederjans [15], Tamiz et al. [17], Taha [16], Fazillah [3], Hassan and Mohammad Basir [6], Hassan and Sahrin [7], and Hassan and Ayop [5] used goal programming for decision making in various applications. The general priority based GP model (as defined by Ignizio [11]) can be stated as follows:

Find X = (X1, X2, ..., XN) so as to,

Minimise $P_j\left(\sum_{i=1}^{m} w_{ij}^- d_{ij}^- + w_{ij}^+ d_{ij}^+\right)$,

Minimise $P_2\left(\sum_{i=1}^{m} w_{ij}^+ d_{ij}^- + w_{ij}^- d_{ij}^+\right)$,

: : : 

Minimise $P_J\left(\sum_{i=1}^{m} w_{ij}^- d_{ij}^- + w_{ij}^+ d_{ij}^+\right)$,

subject to $f_i(X) + d_i^- - d_i^+ = b_i$,

and $w_{ij}^-, w_{ij}^+, d_{ij}^-, d_{ij}^+$, $X \geq 0$, $i = 1,2, ..., m$; $j = 1,2, ..., J$.

where $f_j(X), i = 1,2, ..., m$, is the $i$th function (linear) of decision vector $X$, $b_i$ is the aspiration level of the $i$th goal, $P_j\left(J = 1,2, ..., J; J \leq m\right)$ is the $j$th priority factor assigned to the set of goals that are grouped together in the problem formulation, $d_i^-$ and $d_i^+$ are the underachievement and overachievement variables corresponding to the $i$th goal, $w_{ij}^-$ and $w_{ij}^+$ are the numerical weights associated with the underachievement and overachievement variables $d_{ij}^-$ and $d_{ij}^+$ at the priority level $P_j$. Here, $d_{ij}^-$ and $d_{ij}^+$ are renamed for the actual deviational variables $d_{ij}^-$ and $d_{ij}^+$, respectively.

To formulate the model for the problem, the model variables, constants and coefficients are defined as follows.

Decision variables:

$x_n = \text{fertilizer content (n=1,2, ...,N) (kg/ha) in the mixture.}$

Coefficients and constants:

$C_n = \text{unit cost for fertilizer } x_n \text{ (n=1,2, ...,N) in (RM/kg)}$

$A_{nq}^+ = \text{content of nutrient q=1,2, ...,Q in fertilizer } x_n \text{ (%)}$

$U_q^+ = \text{upper limit of nutrient q (q= 1,2, ...,Q) in fertilizer (kg/ha)}$

$L_q^+ = \text{lower limit of nutrient q (q= 1,2, ...,Q) in fertilizer (kg/ha)}$

$T = \text{total fertilizer cost (RM)}$

Note that RM represents the Malaysian currency for Malaysian Ringgit.

Goal constraints:

There are three constraints to be considered in this model namely, total cost, lower and upper limits of nutrient.

1. Total cost: To avoid any types of unwanted expenditure there should be an estimated fertilizer cost (T) for a season. The goal equation can be presented as
\[ \sum_{n=1}^{N} C_n x_n + d_i^- - d_i^+ = T \]

ii. Lower limit of nutrient: To ensure a good yield from the chilli crops, there should be at least, a minimum amount of nutrients in the fertilizer combination. The goal equation can be represented as

\[ \sum_{n=1}^{N} A_n^{(q)} x_n + d_{q+i}^- - d_{q+i}^+ = L^{(q)} \]

iii. Upper limit of nutrient: To avoid any excess application of nutrient in the fertilizer combination, there should be an upper limit for each nutrient in the combination. The goal equation can be presented as

\[ \sum_{n=1}^{N} A_n^{(q)} x_n + d_{Q+q+i}^- - d_{Q+q+i}^+ = U^{(q)} \]

where \( q = 1, 2, \ldots, Q \)

Application:

Currently, there are two methods being applied at chilli plantation. These are fertigation and conventional plantation. Chilli fertigation is a new method and it is a technique where the crops are planted in polybags. Fertigation plantation is popular among entrepreneurs but incurred a very high cost in the beginning in order to set up the fertigation set. There are only two types of fertilizers used for chilli fertigation namely type A and type B.

Conventional plantation is a common method requiring the crops to be planted directly to the soil. Currently, there are two types of fertilizers being used, namely 10 tonne/ha of chicken waste and 2 tonne/ha of NPK Blue. Chicken waste cost them RM 1800 (RM9 per 50 kg) and NPK blue RM 5600 (RM140 per 50kg).

Since most of the readymade fertilizers for chilli plant available in the market are too expensive, this case study intends to provide an alternative by determining proper fertilizer combination so that farmers will have a proper management toward nutrient required for normal growth and completion of life cycle of the chilli plant and at the same time can reduce their current cost.

The minimum cost of fertilizer can be obtained with the application of N–P–K (Nitrogen-Phosphorus-Potassium) through different fertilizers as described in the Table 1. The maximum and minimum requirements of those nutrients are recommended by the Agriculture Department as 80–140 kg/ha of N, 75–125 kg/ha of P, and 60–120 kg/ha of K. Data are collected from the Farmer Association of Gombak and Petaling District. The costs (\( C_n \)) and composition of the available fertilizer mixtures are shown in Table 1.

Table 1: Fertilizer content.

<table>
<thead>
<tr>
<th>Variables (in kg)</th>
<th>Fertilizer</th>
<th>N (%)</th>
<th>P (%)</th>
<th>K (%)</th>
<th>Price (RM/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>( X_1 )</td>
<td>Urea</td>
<td>45</td>
<td>0</td>
<td>0</td>
<td>1.70</td>
</tr>
<tr>
<td>( X_2 )</td>
<td>NPK Green</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>2.90</td>
</tr>
<tr>
<td>( X_3 )</td>
<td>NPK Blue</td>
<td>12</td>
<td>12</td>
<td>17</td>
<td>2.90</td>
</tr>
<tr>
<td>( X_4 )</td>
<td>Ammonium Phosphate</td>
<td>11</td>
<td>48</td>
<td>0.2</td>
<td>9.50</td>
</tr>
<tr>
<td>( X_5 )</td>
<td>Ammoniated Superphosphate</td>
<td>5</td>
<td>19</td>
<td>0</td>
<td>0.85</td>
</tr>
<tr>
<td>( X_6 )</td>
<td>Potassium Chlorite</td>
<td>0</td>
<td>0</td>
<td>61</td>
<td>7.30</td>
</tr>
<tr>
<td>( X_7 )</td>
<td>Sodium Nitrate</td>
<td>16</td>
<td>0</td>
<td>0.2</td>
<td>3.56</td>
</tr>
<tr>
<td>( X_8 )</td>
<td>Triple Superphosphate</td>
<td>0</td>
<td>46</td>
<td>0.4</td>
<td>3.50</td>
</tr>
</tbody>
</table>

Constraints:

i. Total Cost

\[ \sum_{n} C_n x_n + d_i^- - d_i^+ = T \quad \text{for } n = 1, 2, \ldots, 8 \]

ii. Lower limit of nutrients of nitrogen, phosphorus and potassium

\[ \sum_{n} A_n^{(q)} x_n + d_{q+i}^- - d_{q+i}^+ = L^{(q)} = 60 \]

\[ \sum_{n} A_n^{(5)} x_n + d_{6}^- - d_{6}^+ = L^{(5)} = 80 \]

\[ \sum_{n} A_n^{(5)} x_n + d_{5}^- - d_{5}^+ = L^{(5)} = 75 \]

iii. Upper limit of nutrients of nitrogen, phosphorus and potassium

\[ \sum_{n} A_n^{(q)} x_n + d_{q+i}^- - d_{q+i}^+ = U^{(q)} = 140 \]

\[ \sum_{n} A_n^{(5)} x_n + d_{6}^- - d_{6}^+ = U^{(6)} = 125 \]

\[ \sum_{n} A_n^{(5)} x_n + d_{5}^- - d_{5}^+ = U^{(5)} = 120 \]

for \( n = 1, 2, \ldots, 8 \)
Priority Structure:

After consulting the company’s management, the deviation variables to be minimized are prioritized as follows: first $d_1^+$, second $d_2^+ + d_3^- + d_4^-$, and third $d_5^+ + d_6^+ + d_7^-$. The highest-priority goal is to minimize the overachievement of total cost in fertilizer combination, the second-priority goal is to minimize under utilization of the lower limit of nutrients, while the third priority goal is to minimize the over utilization of the upper limit of nutrients. This can be structured as:

\[
\begin{align*}
P_1: & \quad \text{Minimize the total cost goal in fertilizer combination; } \text{Minimize } (d_1^-) \\
P_2: & \quad \text{Minimize under utilization of the lower limit of nutrients; } \text{Minimize } (d_2^+ + d_3^- + d_4^-) \\
P_3: & \quad \text{Minimize over utilization of the upper limit of nutrients; } \text{Minimize } (d_5^+ + d_6^+ + d_7^-)
\end{align*}
\]

Results:

The problem has been executed using GP software package in LINDO 6.1. The priority achievements corresponding to the optimum decision are displayed in Table 2.

<table>
<thead>
<tr>
<th>Priorities</th>
<th>Description</th>
<th>Achievement</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>Minimize the total cost goal in fertilizer content</td>
<td>Achieved and cost reduced by 78.61 % per hectare</td>
</tr>
<tr>
<td>P2</td>
<td>Minimize under utilization of the lower limit of nutrients</td>
<td>Achieved</td>
</tr>
<tr>
<td>P3</td>
<td>Minimize over utilization of the upper limit of nutrients</td>
<td>Achieved</td>
</tr>
</tbody>
</table>

Hence, the corresponding optimal solution is

\[
\begin{align*}
X_1^- & = (\text{Urea, 45-0-0}) = 177.778 \text{ kg/ha} \\
X_6^- & = \text{(Potassium Chlorite, 0-0-61)} = 97.292 \text{ kg/ha} \\
X_8^- & = \text{(Triple Superphosphate, 0-46-0.4)} = 163.043 \text{ kg/ha}
\end{align*}
\]

The fertilizer content to be applied include 80 kg/ha of Nitrogen, 75 kg/ha of phosphorus and 60 kg/ha of potassium and the cost of combination of the above fertilizer content is RM1583.1047. Moreover, it is observed that with the above combination, the cost of fertilizer used for chilli plantation can be reduced from RM 7400 to RM1583.1047 per hectare.

The highest-priority goal to minimize the overachievement of total cost in fertilizer combination was achieved when $d_1^-$ is 0 and the total cost is reduced by RM 5816.8953 since $d_1^-$ is 5816.8953 which means the cost is reduced from RM 7400 to RM1583.1047 per hectare. The second-priority goal to minimize under utilization of the lower limit of nutrients was achieved when $d_2^+$, $d_3^-$ and $d_4^-$ are all 0. Finally, the third priority goal to minimize the over utilization of the upper limit of nutrients was also achieved when the positive deviation variables $d_5^+$, $d_6^+$ and $d_7^-$ are all zeros.

Conclusion:

This study attempts to deal with the nutrient management problem using goal programming model. The methodology for optimum fertilizer combinations presented in this paper is found to be useful for agricultural planners who can advise farmers on fertilizer nutrient combinations. It is shown that along with maintenance of soil fertility the cost of fertilizer combination for chilli production can be reduced. The work on chilli production based on nutrient management can be extended further to other solanaceae plants such as capsicum, tomatoes and egg plants.

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School of Mathematical Sciences, Universiti Kebangsaan Malaysia (in Malay).


