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NUTRIENT MANAGEMENT FOR RUBBER PLANTATION USING GOAL PROGRAMMING

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Abstract: Farm management must have proper planning on the resources such as fertiliser, labour, water and pesticide. Fertiliser provides healthy growth to the plant. It is one of the important resources the farm needs. Thus, the usage and allocation of fertilisers must be managed wisely to avoid wastage that incurs costs. This paper presents a case study which focuses on the nutrient management of rubber plantations. The main objective is to minimise the cost of chemical fertilisers used to plant rubber. Besides, the sub-objectives are to determine the best weight combination for fertilisers and calculate the mass per hectare of Nitrogen, Phosphorus, and Potassium needed for the rubber trees. The goal programming approach has been applied to solve the problem. In the model formulation, there are seven decision variables representing chemical fertilisers, while the constraints are the cost of chemical fertilisers and the requirement of the upper and the lower limit of nutrients in the chemical fertilisers. Results indicate that this method can meet all the goals expected. In conclusion, this study shows that goal programming is suitable for modelling plant input, cost and constraint of rubber farm management.

Keywords: Nutrient management, goal programming, optimisation, fertiliser.

Introduction

Rubber, or its scientific name *Hevea brasiliensis,* originates in Brazil (Britannica, n.d.). The basic characteristic of rubber is that if it is twisted or stretched, it will return to its original shape. However, it will not return to its original shape if heat is applied to the rubber. A rubber tree will undergo two phases of life: immature and mature. The immature phase begins after the tree is planted on the ground until 4 to 6 years, while the remaining years are called the mature phase. A rubber tree can live for 20 to 40 years and grow to 18 meters in height.

Malaysia has soil fertility and a tropical climate where it experiences humid and hot weather throughout the year, allowing rubber tree growth. Based on recent data, rubber production in 2019 has increased to 640 thousand metric tons compared to 2018 with 603 thousand metric tons (Muller, 2020). Therefore, the larger amount of rubber production makes Malaysia among the biggest producers of natural rubber in the world.

Improving the quality and performance of agricultural activities, followed by product quality and consistency, is one of the objectives that should be achieved by agricultural companies (Africa *et al*., 2020). The efficiency and effectiveness of the process could improve the amount of rubber production. One of the ways is by optimising the use of resources involved in rubber plantation such as fertilisers. There are two types of fertiliser which are organic and chemical fertilisers. The application of fertiliser, either organic or chemical, is one of the methods to improve rubber production. The compound chemical fertilisers contain macronutrients such as nitrogen (N), phosphorus (P) and potassium (K) in a ratio of 12:12:17 or 15:15:15. Meanwhile, incomplete chemical fertilisers lack one of the major nutrients. The nutrient is supplied in the form of Muriate of Potash (MOP), urea, Christmas Island Rock Phosphate (CIRP), triple superphosphate (TPS), and ammonium sulphate. Each fertiliser has a different percentage weight of nutrients that is labelled on the packaging.

Nitrogen, Phosphorus, and Potassium, or NPK, are called macronutrients as they are needed in a large quantity compared to other nutrients. They are also necessary elements in the plantation of rubber to maintain the growth of the plant. Soil nutrient is not enough to support the growth and production of a plant; thus, the usage of chemical fertilisers cannot be denied among planters nowadays. Chemical fertilisers can bring pros and cons not only to the soil but also to the environment. Thus, the usage of chemical fertiliser must be managed wisely by planters in order to sustain the fertility of the soil as well as protect the environment. This practice will benefit the planters as the profits will be increased due to the optimum usage of fertilisers.

In UiTM Perlis's farms, plenty of crops such as coconut, banana, mango, guava, and rubber are planted. Since these plants share the same resources, the management of the Farming Unit of UiTM Perlis has to manage their allocation wisely to avoid wastage that can lead to a loss of profit.

Scientific advances and researchers' efforts nowadays have created new forms of planning in which it is possible to find the best approaches to achieve goals while considering limited resources (Mohammadian & Heydari, 2019). Goal programming is one of the methods to evaluate multi-objective nutrient management decisions subject to constraints and priority. Goal programming has also been practised in many real-world problems such as rubber plantation planning, optimisation of items management in bank financial statements, optimisation of production planning for bakery, and fund allocation of the library.

A study by Qu et al. (2019) has developed an optimisation model that balances between minimising dietary costs and using water for dietary irrigation. Weighted goal programming models were developed for hypothetical cows under 8 environmental scenarios. The solutions decide the cost, water usage and feed required for different feeding options. This framework could be used for different livestock production systems in the future.

Mubiru *et al*. (2020) have proposed a goal programming model for resource allocation in geothermal energy projects. This model was developed to determine the combination of time, labour and materials with the total resources available to complete the projects involving three stages. Results reveal that the model provides satisfactory levels of achievement for all the projects involved.

Sen & Nandi (2012) reported in their research paper that the goal programming approach could be used in the plantation and production of rubber. Their research paper has addressed many goals, including survived trees, expenditure, paid and unpaid workers, and the use of chemical and bio-fertilisers. The results of the study present a model which can be formulated in order to find mature trees that will produce latex for seven years.

Besides, goal programming has been applied to managing other plantations such as chilli, pineapple and cucumber (Hassan *et al*., 2012a; 2012b; 2013b). This goal programming model helps farmers to choose a suitable fertiliser in order to fulfil the requirements of plant growth and production. On the other hand, Ghosh *et al*. (2005) obtained more information from the results of fertiliser combinations, such as the cost of fertiliser combinations and the expected yield of rice production.

In addition, goal programming can be applied in other applications such as production and the banking sector (Hassan *et al*., 2013c; Halim *et al*., 2015). This method has also been used to allocate funds for a library according to priorities (Hassan *et al*., 2013a).

Many studies have focused on rubber production planning (Noordin & Baharudin, 2017; Siregar *et al*., 2020; Swathi *et al*., 2020). However, this study specifically limits the scope of nutrient management for rubber trees. The objective of this study is to minimise the cost of fertilisers used to plant rubber trees. This study also aims to determine the best weight combination of fertilisers and the mass per hectare of nitrogen, phosphorus, and potassium needed for the rubber trees.

Materials and Methods

Data Collection

The study is focused on secondary data taken from the Farming Unit of UiTM Perlis and seven types of fertilisers were chosen in this study, which are NPK (15-15-15), NPK (12-12-17), Christmas Island Rock Phosphate (CIRP), Muriate of Potash (MOP), Triple Super Phosphate (TSP), Ammonium Sulphate, and Urea. The data on nitrogen, phosphorus, and potassium composition in every fertiliser and the cost of chemical fertilisers were collected from the Farming Unit of UiTM Perlis. The minimum and maximum requirements of nutrients in NPK fertiliser were obtained from Lembaga Getah Malaysia through an interview process. The data were then analysed using POM-QM software for Windows in order to minimise the cost of chemical fertilisers.

Standard Form of Goal Programming Model

The goal programming model from Hassan *et al*. (2013b) deals with multicriteria decision-making, which contrasts with the linear programming model.

Minimise $Z = \sum_{i=1}^{m} P_i(w_i d_i^- + w_i d_i^+)$ **(1)**

subject to constraints

$$\sum_{i=1}^{m} a_{ij}x_{ij} + d_i^- - d_i^+ = b_i \quad (2)$$

such that

$$x_{ij}, d_i^-, d_i^+ \geq 0 \quad (3)$$

where

Z = objective function
P_i = priority level for each goal,
w_i = weight of the decision variable,
a_{ij} = coefficient associated with variable *j* in the *i*-th goal,
x_{ij} = decision variable *j* in the *i*-th goal,
b_i = aspiration level for the *i*-th goal,
d_i^- = negative deviational variable for the *i*-th goal (underachievement), and
d_i^+ = non-negative deviational variable for the *i*-th goal (overachievement).

Underachievement and overachievement values of goal cannot occur concurrently. Thus, any of these variables must have zero value, such that

$$d_i^- \times d_i^+ = 0$$

All linear programming variables apply both variables for the positive requirement such that

$$d_i^-, d_i^+, x_{ij} \geq 0 \text{ for } i = 1,...,m; \text{ for } j = 1,...,n$$

where there are *m* goals and *n* decision variables.

Model Formulation

Decision of variables:
X_n = ocontent of fertilizer (*n =1,2,...,7*) (kg/ha),

Constants and coefficients:
T = the estimated total cost of fertiliser (RM),
A_n^k = content of nutrient, *k =1,2,3* in fertilizer (%),
C_n = the cost of fertilizer per unit (*n =1,2,...,7*) (RM/kg),
U^k = upper boundary of nutrient, *k =1,2,3* in the fertiliser (kg/ha),
and
L^k = lower boundary of nutrient, *k =1,2,3* in the fertiliser (kg/ha).

Constraints:

The model has three constraints to consider: the total cost, and the requirement of the lower and upper limits of nutrients in the chemical fertilisers.

(1) The total cost of fertilisers should be equal to or less than estimated to avoid undesirable expenditure. The formula is represented as

$$\sum_{n=1}^{7} C_n X_n \leq T$$

which becomes

$\sum_{n=1}^{7} C_n X_n + d_1^- - d_1^+ = T$ allowing for deviations while minimising d_1^+.

(2) The upper boundary of the nutrients avoids excessive use of fertilisers on the rubber tree. The equation is presented as

$$\sum_{n=1}^{7} A_n^k X_n \leq U^k$$

which becomes

$$\sum_{n=1}^{7} A_n^k X_n + d_p^{\ -} - d_p^{\ +} = U^k$$

for $n = 1,2,...,7$ and $p = 2,3,...,7$ that let deviations while minimizing $d_p^{\ +}$.

(3) The lower boundary of the nutrients in the fertilisers ensures that the growth of the rubber tree is at an optimum level. The formula is represented as

$$\sum_{n=1}^{7} A_n^k X_n \geq L^k$$

which becomes

$$\sum_{n=1}^{7} A_n^k X_n + d_p^{\ -} - d_p^{\ +} = L^k$$

for $n = 1,2,...,7$ and $p = 2,3,...,7$ that let deviations while minimizing $d_p^{\ -}$.

There are seven types of fertiliser selected in this study. The composition of chemical fertilisers used in this study is nitrogen (N), phosphorus (P), and potassium (K). The estimated total cost of all UiTM Perlis's farm fertilisers is RM1514. Table 1 shows the types and cost of chemical fertilisers used for the plantation of rubber and the content of NPK for each chemical fertiliser. The information on requirements for the upper and lower limits of nutrients in the fertilisers was recommended by Lembaga Getah Malaysia as described in Table 2.

Equations (4) - (12) show the goal programming model. The model is constructed using the data in Table 1 and Table 2. The top priority goal is to minimise the total cost of chemical fertilisers. The second and third priorities are to minimise the underutilisation of lower-limit and overutilisation of upper-limit nutrients. The priorities are shown below:

Priority structure:

First Priority: Minimise the total cost of chemical fertilisers; *Minimise* $d_1^{\ +}$.

Second Priority: Minimise the underutilisation of lower limit of nutrients; *Minimise* $d_2^{\ +} + d_3^{\ +} + d_4^{\ +}$.

Third Priority: Minimise the overutilisation of the upper limit of nutrients; *Minimise* $d_5^{\ +} + d_6^{\ +} + d_7^{\ +}$.

Table 1: Types of chemical fertiliser used and the content of NPK

Decision Variable (in kg)	Type of Fertiliser	N (%)	P (%)	K (%)	Cost (RM/kg)
X_1	Urea	46	0	0	1.7
X_2	NPK (12-12-17)	12	12	17	3
X_3	NPK (15-15-15)	15	15	15	3
X_4	MOP	0	0	60	1.66
X_5	TSP	0	48	0	2.11
X_6	CIRP	0	36	0	0.92
X_7	Ammonium Sulphate	21	0	0	0.911

Table 2: Lower limit and upper limit of NPK fertiliser

Content of Fertilizer	Lower Limit (kg/ha)	Upper Limit (kg/ha)
Nitrogen (N)	150	180
Phosphorus (P)	110	140
Potassium (K)	90	130

Model Construction

$$\text{Minimized} = P_1d_1^+ + P_2d_2^- + P_2d_3^- + P_2d_4^- + P_3d_5^+ + P_3d_6^+ + P_3d_7^+ \quad \textbf{(4)}$$

Estimate cost of fertilisers:

$$1.70X_1 + 3.00X_2 + 3.00X_3 + 1.66X_4 + 2.11X_5 + 0.92X_6 + 0.911X_7 + d_1^- - d_1^+ = 1514 \quad \textbf{(5)}$$

Lower limits of Nitrogen (N) - Phosphorus (P) - Potassium (K)

$$0.46X_1 + 0.12X_2 + 0.15X_3 + 0.21X_7 + d_2^- - d_2^+ = 150 \quad \textbf{(6)}$$

$$0.12X_2 + 0.15X_3 + 0.48X_5 + 0.36X_6 + d_3^- - d_3^+ = 110 \quad \textbf{(7)}$$

$$0.17X_2 + 0.15X_3 + 0.6X_4 + d_4^- - d_4^+ = 90 \quad \textbf{(8)}$$

Upper limits of Nitrogen (N) - Phosphorus (P) - Potassium (K)

$$0.46X_1 + 0.12X_2 + 0.15X_3 + 0.21X_7 + d_5^- - d_5^+ = 180 \quad \textbf{(9)}$$

$$0.12X_2 + 0.15X_3 + 0.48X_5 + 0.36X_6 + d_6^- - d_6^+ = 140 \quad \textbf{(10)}$$

$$0.17X_2 + 0.15X_3 + 0.6X_4 + d_7^- - d_7^+ = 130 \quad \textbf{(11)}$$

$$X_1, X_2, X_3, X_4, X_5, X_6, X_7, d_1^-, d_2^+, d_2^-, d_3^+, d_3^-, d_4^+, d_4^-, d_5^+, d_5^-, d_6^+, d_6^-, d_7^+, d_7^- \geq 0 \quad \textbf{(12)}$$

Results and Discussion

The goal programming model was analysed and the final solution was obtained. Table 3 shows the value of decision variables according to the types of fertiliser. It presents the results of goal programming which the optimal value is = 326.09, = 150, = 229.17. This means that three types of chemical fertilisers can be used for the plantation of rubber, which are 326.09 kg/ha of Urea (46-0-0), 150 kg/ha of MOP (0-0-60), and 229.17 kg/ha of TSP (0-48-0).

Additionally, Table 4 presents the results of the constraints analysis. In the constraints analysis, entails the goal of underachievement or negative deviation of goal while constitutes the goal of overachievement or positive deviation from the goal. The priorities of achievement that correspond with the optimal decision are displayed in Table 5. Priority analysis results present whether the goals can be achieved or not. Based on Tables 4 and 5, the approximate cost reduction is by 15% from RM1491.14 to RM1264.03, where the cost has been decreased by RM227.11. This can be seen when This means that the priority which is to minimise the total cost of chemical fertilisers, has been fully achieved when . The cost reduction is in line with the results reported by other publications in the literature (Hassan *et al*., 2012a; 2012b; 2013b; Agustina *et al*., 2015). The second priority is to minimise the underutilisation of the lower limit of nutrients is fully achieved when the negative deviational variables = 0. The values are given in rows two to four of the third column in Table 4. Finally, the values in rows five to seven of the second column in Table 4 indicate that the third priority, that is to minimise the overutilisation of the upper limit of nutrients, has been fully achieved when the positive deviational variables = 0. This study has generally achieved its priorities (the non-achievement is 0).

Table 3: Results of decision variables

Decision Variable	Type of Fertiliser	Value (kg/ha)
X_1	Urea	326.09
X_2	NPK 12-12-17	0
X_3	NPK 15-15-15	0
X_4	MOP	150
X_5	TSP	229.17
X_6	CIRP	0
X_7	Ammonium Sulphate	0

Table 4: Results of constraints analysis

Constraint Analysis	d_i^+	d_i^-
Cost of Fertilizers (RM/kg)	0	227.11
Lower Limit of Nitrogen	0	0
Lower Limit of Phosphorus	0	0
Lower Limit of Potassium	0	0
Upper Limit of Nitrogen	0	30
Upper Limit of Phosphorus	0	30
Upper Limit of Potassium	0	40

Table 5: Priorities of achievement

Priority Analysis	Description	Conclusion
First priority	Minimise the total cost of chemical fertiliser	Fully achieved, $d_1^+ = 0$ since $d_1^- = 227.11$
Second priority	Minimise the underutilisation of the lower limits of nutrients	Fully achieved, value = 0, since $d_2^-, d_3^-, d_4^- = 0$
Third priority	Minimise the overutilisation of the upper limit of nutrients	Fully achieved, value = 0, since $d_5^+, d_6^+, d_7^+ = 0$

In addition, Table 6 expresses the mass per hectare of NPK applied. According to the results, Urea has the highest value of compound applied which is 150 kg/ha. Thus, nitrogen consumption is greater than the other nutrients in fertilisers.

Furthermore, Table 7 and Figure 1 show the comparison of types and weights of fertiliser by using the current practice and the results of using the goal programming method based on selected fertilisers under study. Even though the types of fertiliser in the current practice are not the same as the results from goal programming, it will not affect the growth of the rubber trees because the composition of Nitrogen, Phosphorus, and Potassium in chemical fertilisers is at an optimum quantity. The amount of mass per hectare of NPK compound is within the lower and upper boundaries. In the current practice, the usage of CIRP (0-36-0) is the highest among the other fertilisers, while for the goal programming results, the consumption of Urea (46-0-0) in rubber plantation is greater compared to MOP and TSP.

Table 6: Compound of NPK

Types of Fertilisers	Value (kg/ha)	Percentage of NPK Compound (%)	Mass per Hectare of NPK (kg/ha)
Urea	326.09	46% of Nitrogen	150
TSP	229.17	48% of Phosphorus	110
MOP	150.00	60% of Potassium	90

Table 7: Comparison of allocation of fertilisers used for current practice and goal programming

Current Practice		**Goal Programming Results**	
Type of fertiliser used	**Weight of the fertiliser (kg/ha)**	**Type of fertiliser used**	**Weight of the fertiliser (kg/ha)**
Urea (46-0-0)	320.00	Urea (46-0-0)	326.09
CIRP (0-36-0)	490.00	MOP (0-0-60)	150.00
MOP (0-0-60)	299.00	TSP (0-48-0)	229.17

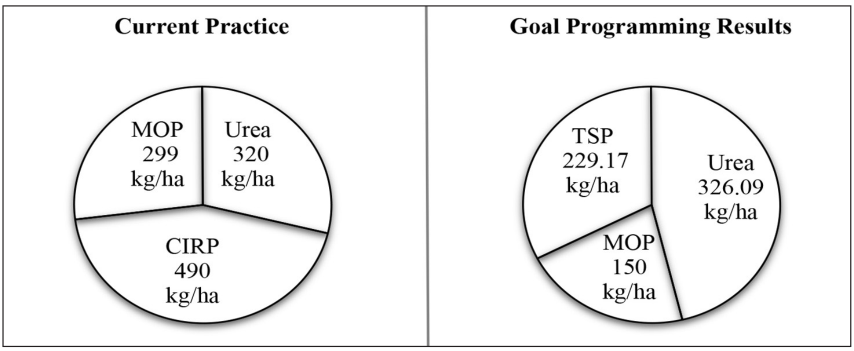

Figure 1: Allocation of fertilisers between current practice and goal programming results based on selected fertilisers

Conclusion

Managing financial resources is becoming more challenging nowadays. All organisations need to have proper planning for their expenses. Good resource management is a must in every organisation since the resources involve cost and will affect the profit earned. Therefore, the optimum allocation of resources can help the organisation to achieve its goals and objectives. The problem of optimisation of nutrient management is a major concern to any plantation sector. Many methods can be used; however, goal programming is suitable for optimising nutrient management. Therefore, this study was conducted by applying a mathematical technique which helps the Farming Unit of UiTM Perlis find the optimum combination of fertiliser content and obtain the appropriate types of fertiliser needed to optimise nutrient management for rubber plantation. The data collected were analysed using the goal programming model. Based on the results, the priority to minimise the cost of fertiliser use has been fully achieved. The significant reduction in fertiliser cost is RM227.11, from RM1491.14 to RM1264.03. The second and third priorities are also fully achieved. The second and third priorities are to minimise the underutilisation of the lower limit and the overutilisation of the upper limit of nutrients. These goals ensure that the results obtained are within the limits of the lower and upper boundaries of needed nutrients. In general, this study has achieved all of its priorities. In addition, it can be seen that the optimum uses of fertilisers are 150 kg/ha, 110 kg/ha, and 90 kg/ha for nitrogen, phosphorus, and potassium, respectively. It was observed that

Urea, MOP, and TSP are the types of fertiliser that should be used in rubber plantations. Furthermore, the study has accomplished its objectives: minimise the cost of fertilisers, determine the best combination of weight for fertilisers used on rubber trees, and calculate the mass per hectare of nitrogen, phosphorus, and potassium needed for rubber trees. Therefore, it is proven that the goal programming approach is a useful and effective technique to guide farmers in reducing the cost of fertilisers, thus growing their income.

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References

Africa, A. D. M., Abaluna, D. A. P., & Pimentel, K. D. P. (2020). Monitoring and control systems in agricultural machineries and equipment with a Low-Power Smart Antenna System. *International Journal of Emerging Trends in Engineering Research*, *8*(5), 1860-1868.

Agustina, R., Saleh, H., & Gamal, M. D. H. (2015). Modeling oil palm nutrient management using linear goal programming. *Applied and Computational Mathematics*, *4*(5), 374-378.

Britannica. (n.d.). *Rubber: Chemical Compund*. Retrieved Jan 9, 2019, from https://www.britannica.com/science/rubber-chemical-compound/Tapping-and-coagulation

Ghosh, D., Sharma, D. K., & Mattison, D. M. (2005). Goal programming formulation in nutrient management for rice production in West Bengal. *International Journal of Production Economics*, *95*(1), 1-7.

Halim, B. A., Karim, H. A., Fahami, N. A., Mahad, N. F., Nordin, S. K. S., & Hassan, N. (2015). Bank financial statement management using a Goal Programming Model. *Procedia - Social and Behavioral Sciences*, *211*, 498-504.

Hassan, N., Azmi, D. F., Guan, T. S., & Hoe, L. W. (2013a). A Goal Programming Approach for library acquisition allocation. *Applied Mathematical Sciences*.

Hassan, N., Hassan, K., Yatim, S., & Yusof, S. (2013b). Optimizing fertilizer compounds and minimizing the cost of cucumber production using the Goal Programming Approach. *American-Eurasian Journal of Sustainable Agriculture*, *7*(2), 45-49.

Hassan, N., Md Pazil, A. H., Idris, N. S., & Razman. (2013c). A Goal Programming Model for bakery production. *Advances in Environmental Biology*, *7*(1), 187-190.

Hassan, N., Safiai, S., Raduan, N. H. M., & Ayop, Z. (2012a). Goal programming formulation in nutrient management for chilli plantation in Sungai Buloh, Malaysia. *Advances in Environmental Biology*, *6*(12), 4008-4012.

Hassan, N., & Sahrin, S. (2012b). A mathematical model of nutrient management for pineapple cultivation in Malaysia. *Advances in Environmental Biology*, *6*(5), 1868-1872.

Mohammadian, F., & Heydari, M. (2019). Application of fuzzy goal programming to determine the Optimal Cultivation Crops Model. *International Journal of Students' Research in Technology & Management*, *7*(1), 01-08.

Mubiru, K. P., Senfuka, C., & Ssempijja, M. N. (2020). A Goal Programming Approach to resource allocation in Geothermal Energy Projects. *International Journal of Academic and Applied Research*, *4*(6), 50-53.

Muller, J. (2020). Malaysian Total Rubber Production 2000-2019.

Noordin, N., & Baharudin, S. (2017). A Linear Programming Approach to optimize natural rubber production. *Journal of Computing Research and Innovation*, *2*(1), 50-55.

Qu, J., Hsiao, T. C., DePeters, E. J., Zaccaria, D., Snyder, R. L., & Fadel, J. G. (2019). A

Goal Programming Approach for balancing diet costs and feed water use under different environmental conditions. *Journal of Dairy Science*, *102*(12), 11504-11522.

Sen, N., & Nandi, M. (2012). A Goal Programming Approach to rubber plantation planning in Tripura. *Applied Mathematical Sciences, 6*(124), 6171-6179.

Siregar, I., Rizkya, I., Sari, R. M., & Syahputri, K. (2020). Optimal production quantity in rubber industry. *IOP Conf. Series: Materials Science and Engineering*, *851*(1).

Swathi, A. S., Praveena Kumara, K. M., Uday Kumar, K. N., & Harish Babu, G. A. (2020). A Goal Programming Model for rubber plantation planning in Western Ghats of Karnataka. *International Journal of Mechanical and Production Engineering Research and Development*, *10*(2), 13897-13903.