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APPLICATION OF LINEAR PROGRAMMING MODELS FOR OPTIMAL RESOURCE PLANNING AND MANAGEMENT IN SUSTAINABLE CULTIVATION - A CASE STUDY IN A FARMING VILLAGE OF SRI LANKA

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Abstract

As an agrarian based economical country, objective of Sri Lankan cultivation is not only for consumption, but also for earning net profit from the agriculture. To obtain maximum net return from the cultivation, there should be proper cultivation plan which utilizes the resources optimally. This study aims at optimizing the land resource by considering requirements of the cultivation in order to obtain maximum net return using a linear programming model. This study was carried out in a farming village located in Dompe Divisional Secretariat in Gampaha District, Sri Lanka by considering 24 selected crops under three categories as vegetables: brinjal, chilies, luffa, winged bean, tomatoes, bitter gourd, bird chili, lady's fingers, snake guard, manioc, taro, fruits: rambutan, banana, pineapple, Gadiguda, durian fruit and, other: lemongrass, beetle, rice, beetle nut, coconut, tea, rubber and pepper. A linear programming model is formulated for

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optimal land resource allocation of 18745.33 perches by considering following constraints: land resource availability, water requirement, cost for fertilizers and labor hours. There is 5.79% thrift of profit from the proposed cultivation plan compared to the actual profit of the cultivation. Actual allocated amount of land area of vegetables, fruits and other variety are 32.3%, 29.2% and 38.6%, respectively, which has been changed to 30.9%, 31.5% and 37.6%, respectively, by the proposed linear programming model. The proposed model suggests that the maximum increment of the profit can be obtained by extending the rambutan cultivation. Harvest amount obtained from the proposed model for vegetables, fruits and other variety are 95986 kg, 38393.2 kg and 16656.9 kg, respectively. Finally, this study suggests to optimally develop and extend the cultivation of crops which can earn maximum net return.

Introduction

Planning involves a series of steps that determine the best ways to solve a problem, achieve some desired goal or create required objectives. Optimal resource planning in cultivation refers to the procedure/action of making the best or most effective use of the resource for the cultivation in sustainable manner in order to obtain the maximum net return. Sustainability is a composite concept that incorporates economic, social and environmental aspects. Agriculture sector plays a major role in Sri Lankan economy. Traditional farming is a proud industry in Sri Lanka. Traditional farming knowledge and tools are all passed out from generation to generation. Even though farmers are rich with farming knowledge, still there is a lack of cultivation plans and resource management techniques for rural areas. Reaching an efficient cultivation plan, utilization of resources and requirements often lead to a difficult and challenging problem, wherein finding the solution is necessary. Hundreds of hard hours are invested in growing crops and for many farming families' cultivation is their only source of income. Yield wastage provides a serious impact on their families' consumption and also on earnings. Population increases day by day. To fulfill the demand for foods for the increasing population from the limited

resources is a key issue being tackled globally. Therefore, it is necessary to manage resources required for the cultivation effectively (Soltani et al. [9]). There are numerous research articles about design-support tools, models and methodologies which can be used to manage resources effectively in cultivation (Peltonen-Sainio et al. [6]). Key objectives of the cultivation planning are maximization of profit with minimization of the investments, utilization of the resources and other constraints (Patel et al. [5]). Mathematical programming models play an important role in assessing the optimal cultivation plan. Most popular model used to optimize resources under single objective is the linear programming (LP) model (Shreedhar [8]). The objective of the linear programming model is to maximize or minimize the objective function under several constraints. Linear programming models have been used to optimize the water usage for farming (Difallah et al. [2]), allocation of land resource for multiple crops optimally (Lunge [4]), maximize the net profit from the cultivation (Hamsa et al. [1]) and minimize the cost of production (Herath and Samarathunga [3]).

The objective of this research is to maximize the net return of the cultivation using linear programming technique and allocate the arable land optimally by utilizing water requirement, manpower and cost of fertilizers. Linear programming is a most convenient and effective tool to handle the objective function with many number of constraints (Porchelvi and Irine [7]). This study was carried out to allocate the land resource optimally for 24 selected crops namely: Brinjals (*Solanum melongena*), chilies (*Capsicum annuum*), Luffa (*Luffa aegyptiaca*), wined beans (*Psophocarpus tetragonolobus*), tomatoes (*Lycopersicon esculentum*), Bitter gourd (*Momordicacharantia*), Bird chili (*Capsicum frutescens*), Lady's fingers (*Abelmoschusesculentus*), Snake gourd (*Trichosanthes cucumerina*), Manioc (*Manihot esculenta*), Taro (Colocasia) (*Colocasia esculenta*), Rambutan (*Nepheliumlappaceum*), Banana (*Musa paradisicum*), Pineapple (*Ananussativus*), Gadiguda (*Baccaurea motleyana*), Durian fruit (*Durio*), lemongrass (*Cymbopogon*), Betel (*Piper betle*), Rice (*Oryza sativa*), Betel nut (*Areca catechu*), Coconut (*Cocos nucifera*), Tea (*Camellia sinensis*), Rubber (*Heveabrasiliensis*) and Pepper (*Piper nigrum*). Each crop can be

described in terms of variety of crops (i.e., vegetable, fruit or other) and season (number of months for cultivation). Cultivation plan is a timely requirement which directly or indirectly influences the development of social and economic sector. This study was carried out in a farming village located in Dompe Divisional Secretariat in Gampaha District of Sri Lanka.

Methodology/Materials and Methods

Linear programming model illustrated in Table 1 was used to obtain maximum net return from multicrop cultivation by allocating the land optimally under the following constraints: land resource allocation for each crop, water requirement for cultivation, cost of fertilizer and labor hour.

Table 1. Objective function and constraints

Objective function	
Maximize the net return or profit	$Max\ Z = \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K}(I_{ijk} - C_{ijk})\,a_k x_{ijk}$
Constraints	
Land resource availability for crop cultivation	$\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K} a_k x_{ijk} = X$
Water requirement for cultivation	$\sum_{i=1}^{I}\sum_{j=1}^{J} w_{ijk} a_k x_{ijk} \le W_{ijk},\ \forall k$
Cost of fertilizer for cultivation	$\sum_{i=1}^{I}\sum_{j=1}^{J} f_{ijk} a_k x_{ijk} \le F,\ \forall j$
Labor hours for cultivation	$\sum_{i=1}^{n} l_{ijk} a_k x_{ijk} \le L,\ \forall j,\ k$
Non-negative constraint	$x_{ijk},\ y_{ijk},\ p_{ijk},\ c_{ijk},\ w_{ijk},\ f_{ijk},\ l_{ijk},\ a_k \ge 0$

where

Z - net return from production of all crops grown in study area in kg,

x_{ijk} - area of cultivable land for *i*th variety of crop in *j*th season of *k*th crop in study area (decision variables),

X - total land area,

i - index of the variety of crop, j - Index of the season, k - Index of the crop name,

I_{ijk} - income gained per unit area of kth crop in season j under the variety of crop i in rupees,

C_{ijk} - cultivation or maintenance cost per unit area of kth crop in season j under the variety of crop i in rupees,

w_{ijk} - water requirement per unit area of ith crop in month j under the variety of crop k,

W_{ijk} - total water availability in the study area,

f_{ijk} - cost for fertilizer required per unit area of ith crop in month j under variety of crop k rupees,

F - total cost of fertilizers in rupees,

l_{ijk} - labor hours required per unit area of ith crop in month j under the variety of crop k in rupees,

L - total labor hours

$$a_k = \begin{cases} 1; & \text{if } k\text{th crop will be cultivated,} \\ 0; & \text{if } k\text{th crop will not be cultivated.} \end{cases}$$

The decision variables are the optimal areas of land allocated to each of the crops to cultivate under the objective of obtaining maximum profit for the selected study area. The net return of the cultivation was calculated by subtracting the cost of cultivation from the income of the cultivation.

Data Analysis and Results

Table 2 represents the details of the crops including variety of each crop with the period of cultivation. The linear programming model is formulated

for optimal land resource allocation of 18745.33 Perches by considering several constraints. The decision variables are the optimal areas of land allocated to each crop. Proposed model provides a total profit of Rs. 4808067.

Table 2. Illustration of the indices of the decision variables

i	**Variety of crops**	j	**Season (month)**	k **(Crop)**	X_{ijk}	**Crop**	**Actual area (Perches)**	**Calculated are (Perches)**
1	Vegetables	1	2	1	X_{111}	Brinjal	125	150
				2	X_{112}	Chilies	140	180
				3	X_{113}	Luffa	220	250
				4	X_{114}	Winged bean	170	180
		2	4	1	X_{121}	Tomatoes	100	105
		3	6	1	X_{131}	Bitter gourd	480	500
				2	X_{132}	Bird chili	316	358
				3	X_{133}	Lady's fingers	1648	1742.3
				4	X_{134}	Snake Guard	136	150
		4	8	1	X_{141}	Manioc	2074	1500
		5	12	1	X_{151}	Taro	640	680
2	Fruits	4	8	1	X_{241}	Rambutan	1797	2120
		5	12	1	X_{251}	Banana	738.33	780
		6	18	1	X_{261}	Pineapple	2560	2500
				2	X_{262}	Gadiguda	120	200
		7	36	1	X_{271}	Durian fruit	250	300
3	Other	3	6	1	X_{331}	Lemongrass	160	200
				2	X_{332}	Betel	176	200
		4	8	1	X_{341}	Rice	2577	2800
		5	12	1	X_{351}	Betel nut	120	150
				2	X_{352}	Coconut	1760	1000
		6	18	1	X_{361}	Tea	1355	1500
				2	X_{362}	Rubber	360	400
		7	36	1	X_{371}	Pepper	723	800

Figure 1 represents the allocation of land area for each variety. Further, it compares the actual or the existing allocated land area and area proposed by the linear programming model for each variety. Fruits demonstrate

considerable increment of the allocated land area by proposed model compared to the actual allocated area. But vegetables and other category demonstrate decrement of allocated land area proposed by the model compared to the existing allocated land area.

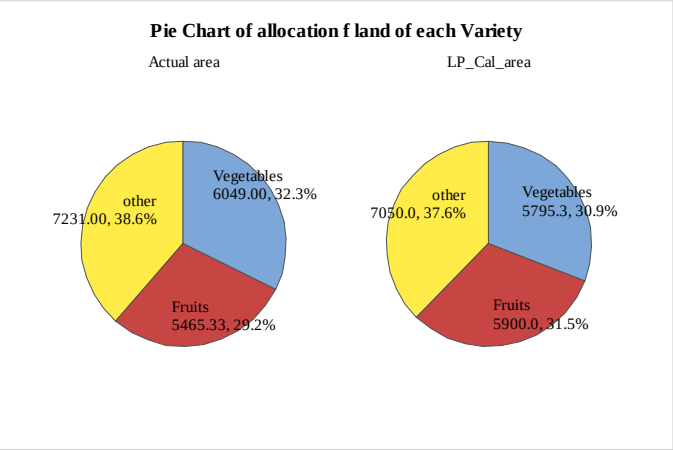

Figure 1. Pie chart of actual and calculated area for each variety.

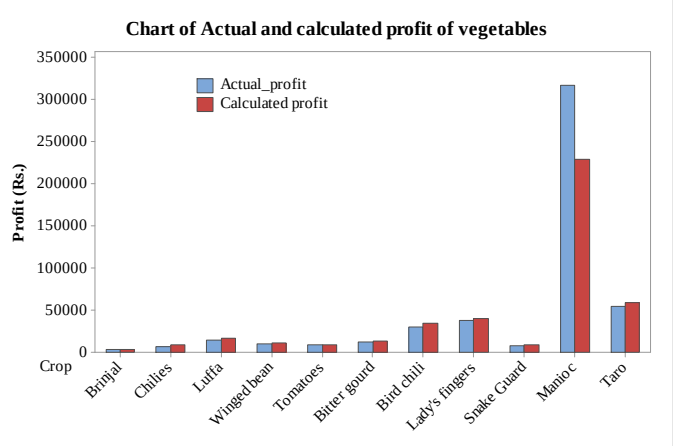

Figure 2. Representation of profit earned from each vegetable.

Figure 2 illustrates comparison of profit obtained from vegetables between proposed model and existing cultivation. According to the optimal land allocation by the proposed model, profits earned by most of the selected

vegetables have increased. Further, proposed model in this study suggests that profit earned by the manioc will be reduced by considerable amount.

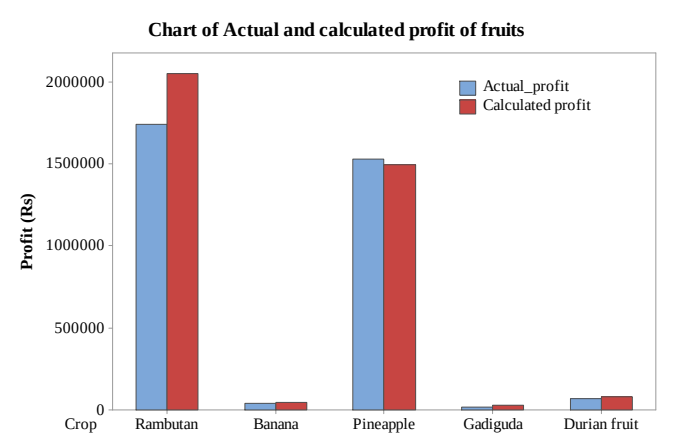

Figure 3. Representation of profit earned from each fruit.

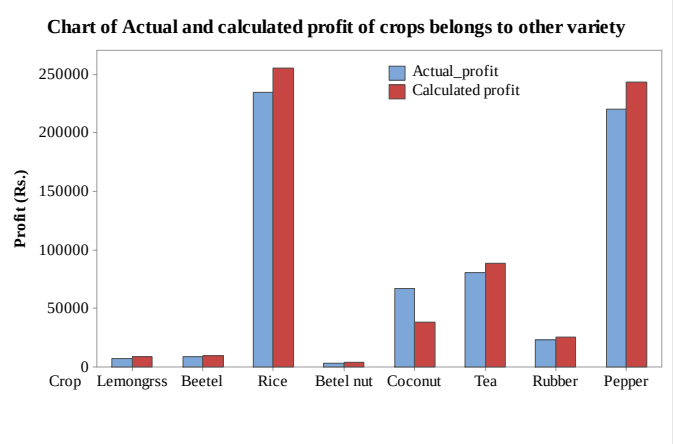

Figure 4. Representation of profit earned from each crop belongs to other category.

According to Figure 3, maximum profit is obtained from rambutan in both actual cultivation as well as proposed cultivation model. Further, profit calculated from the proposed model for pineapple is lower than the profit of existing cultivation. As rambutan and pineapple cultivations exist in large

scale, profit earned by those crops is very high compared to other selected fruits.

There are eight selected crops under the variety ‘other’ including the main plantation in Sri Lanka. Among them, maximum profit is obtained from rice. Calculated profit of the crops belonging to the other variety is higher than the profit obtained from existing cultivation except coconut (Figure 4).

Discussion

In this study, cropped area has been utilized fully by the crops considered for the model. This model aims at allocating arable land area optimally in order to get maximum net return. Water resource is one of the major requirements for the cultivation. 15404.8 M3 per Perch is the maximum allocated water amount for the selected crop cultivation. Cost of fertilizers and labor hours are other considered factors in this model. Period of time required for cultivation for a particular crop is considered as the season of that crop and labor hours are calculated based on the season. Binary variable was used to introduce the *k*th crop to the model representing whether it is cultivated or not.

In this study the existing 1874533 Perches of land area was allocated for vegetables, fruits and other variety, respectively, as 6049 Perches, 5465.33 Perches and 7231 Perches. According to the proposed model, optimal land allocation was 30.9% for vegetables, 31.5% for fruits and 37.6% for other variety. Out of selected 24 crops, the proposed Linear Programming model suggested to allocate maximum land area for Rice. Harvest amount was calculated based on the results of the decision variables and the total harvest amount obtained by 24 crops is 64648.8 kg. Profits obtained from the proposed model for vegetables, fruits and other variety are, respectively, Rs. 432587.7, Rs. 3702257.6 and Rs. 673221.5. Out of fruits selected in this study, profit calculated by proposed model for rambutan is higher than the profit earned by existing rambutan cultivation. There are few crops suggested by the proposed model with lower profit than existing cultivation. These are Manioc, Pineapple and Coconut. But all other crops have

increased the net return compared to the existing cultivation net return. Even though farming period or the season for pepper and durian fruit is very long, it produces considerable net return to the farmers.

Conclusions and Recommendations

The study considered resources and requirements needed for the cultivation to model an agricultural cropping plan. The application of linear programming concept in cultivation planning has utilized land resource optimally under several constraints with 5.79% of increase in profit compared to the existing cultivation. Moreover, out of these selected crops, crops like rice, pepper and rambutan which lead to obtain maximum benefit should be developed and extended for the cultivation under the supervision of the agricultural experts or officers. Percentage of existing allocated land for vegetables and other variety have been reduced by 1.4% and 1%, respectively, with the proposed model. Percentage of existing profit obtained from of crops belonging to fruits and the other variety are increased by 8.97% and 4.6%, respectively, through the proposed model. Moreover, cultivation of maximum amount of crops optimally earns maximum net return is also one of the suggestions of this study. Different crops need different soil conditions. However, this study was limited to consider the soil condition constant for all crops cultivated in the village. Further, this study can be improved by employing advanced operations research techniques like multi-objective nonlinear programming models as future works.

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