Agr. Nat. Resour. 56 (2022) 193–202

AGRICULTURE AND NATURAL RESOURCES

Journal homepage: http://anres.kasetsart.org

Research article

Application of fuzzy goal programming model to assess optimal multi crop cultivation planning

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Article Info

Article history:
Received 8 February 2021
Revised 6 January 2022
Accepted 21 January 2022
Available online 25 February 2022

Keywords:
Fuzzy goal programming,
Optimal cultivation plan,
Tolerance

Abstract

Importance of the work: Planning for the optimal use of resources in agricultural systems considering uncertainty, with the objective of maximizing profit and production, will improve the social and economic conditions of farmers.

Objectives: A rural farming area in Sri Lanka was used as a study site to apply the fuzzy goal programming (FGP) approach to identify the optimal cultivation plan and land resource allocation under uncertainty to optimize profit, production, labor, water use, fertilizer costs and land allocation.

Materials & Methods: A tolerance-based FGP technique was used to quantify the fuzziness of different goals for the model. This study was carried out using 24 crops on a total land area under cultivation of 47.4 ha. These crops were categorized into three varieties: vegetable, fruit and other. Furthermore, the crops were classified into seven groups according to the required period of cultivation.

Results: The proposed model suggested statistically significant increments of 11% and 10.6% for the net return and harvest amount, respectively, for the 24 crops compared to existing cultivation techniques.

Main finding: The FGP multi-crop cultivation planning approach is a new application for the Sri Lankan rural farming community and it should be useful for agricultural planners, by allowing them to make more informed recommendations to the farming community. Crops that provide higher levels of production and profit than those currently being cultivated should be developed to extend cultivation under the supervision of agricultural experts or officers to obtain sustainable development of cultivation.

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https://doi.org/10.34044/j.anres.2021.56.1.18

Introduction

Cultivation planning involves a complex interaction between nature and economics. Optimal cultivation planning is the procedure of making the most effective use of the natural and artificial resources for cultivation in a sustainable manner to achieve desired goals (Sharma et al., 2015). Traditional farming has a proud industry in Sri Lanka, with traditional farming knowledge and tools being passed down from generation to generation. Even though farmers are rich with farming knowledge, there is still a lack of cultivation plans and resource management techniques in rural areas. Achieving an efficient cultivation plan and best utilization of resources often leads to difficult and challenging problems, for which solutions must be found. Hundreds of hours of hard labor may be are invested in growing crops that for many farming families is their only source of income. Thus, one bad yield or yield wastage not only impacts their ability to provide for themselves but can impact their entire community. Feeding an ever increasing population from limited resources is a key issue that has been raised globally; therefore, it is necessary to manage the resources required for cultivation effectively (Soltani et al., 2011). Research articles have discussed design-support tools, models and methodologies that can be used to manage resources effectively in cultivation (Peltonen-Sainio et al., 2019). Key objectives of cultivation planning include maximization of profit and utilization of the resources, with minimization of investment (Patel et al., 2016; Shreedhar, 2018).

Mathematical programming models play an important role in assessing an optimal cultivation plan. The most popular and simplest model that is used to optimize resources under a single objective is linear programing (Difallah et al., 2017). 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 optimizing water usage for farming (Difallah et al., 2017), allocation of land resource for multiple crops (Peltonen-Sainio et al., 2019), maximize the net profit from the cultisvation (Hamsa and Bellundagi, 2018) and minimize the cost of production (Sharma et al., 2015). In a practical sense, it is important to achieve the desired goal instead of achieving a few objectives in planning for a proper cultivation plan. Generally, the procedure of cultivation planning involves multiple goals, such as maximizing profit, maximizing yield, minimizing cost, minimizing the hours of labor and optimizing water requirements and the utilization of the land resource. An objective function is a function that defines some quantity that should be minimized or maximized. An objective in conjunction with an aspiration level is termed a goal. An aspiration level is a specific value associated with an acceptable level of achievement of an objective (Mékidiche et al., 2013). Goal programming is a is a goal-oriented optimization method used to achieve several goals according to related constraints. Furthermore, it can be used to obtain a satisfactory solution which comes closest to meeting the stated goals under given constraints. Goal programming was introduced by Charnes and Cooper (1961) (Sharma et al., 2015). Multi-objective programming techniques and lexico- graphic goal programming have been used by Sharma et al. (2015) to solve agricultural land allocation problems from which they proposed an annual agricultural plan. In general, uncertainties are associated with the parameters related to cultivation. Thus, a fuzzy approach for cultivation planning allows for the vagaries associated with crop profit, production costs, resources and requirements, such as water, labor and machine power.

The mathematical formalization of fuzziness was initiated by Lofti A. Zadeh in the 1960's (Herath and Samarathunga, 2015). Fuzzy goal programing models are commonly used when there are non-aggregated goals in production, changes in goals over time that may be considered in the model and difficulty in defining goals and restrictions in the model (Mohammadian and Heydari, 2019). Bankian-Tabrizi et al., (2012) proposed a fuzzy multi choice goal programming model and its application. In many real world problems, the decision environment is not always clearly defined. Thus, the current study was extended to consider uncertainty of variables using fuzzy optimization. The objective of this research was to propose an optimal cultivation plan using a fuzzy goal programming approach to allocate arable land optimally, while achieving some desired goals (profit, production, labor, water requirement, cost of fertilizers) by considering uncertainty. Thus, the proposed model should be beneficial for the farming community to obtain maximum net return and targeted harvest, while optimizing land resources, labor and water requirements.

Materials and Methods

Model goals were listed and introduced in a membership function to transform the goal programming model into a fuzzy goal programming model. The steps of the formation of the model and notation are given below-:

i – Index of variety of crop
j – Index of season
k – Index of crop name
l – Index of goal
x_{ijk} – Area of cultivable land for i^{th} variety of crop in j^{th} season of k^{th} crop in the study area

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

Model goals

Five goals were considered in the study and each goal is described below in detail.

Profit goal

The decision maker has to allocate the total available land to the crops so that the total profit will be maximized. Profit was calculated by subtracting the production cost from the corresponding income of each crop. Thus, the first goal was formulated using Equation 1:

$$\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K} (I_{ijk} - C_{ijk})\, a_k x_{ijk} \geq P \tag{1}$$

where I_{ijk} is the income gained per unit area of the k^{th} crop in season j under the variety of crop i in rupees, C_{ijk} is the cultivation or maintenance cost per unit area of the k^{th} crop in season j under the variety of crop i in rupees and P is the expected net profit from all crops.

Production goal

To obtain the maximum expected production from crop cultivation, the production goal was expressed using Equation 2:

$$\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K} Y_{ijk}\; a_k x_{ijk} \geq \sum_{k=1}^{K} Y_k \tag{2}$$

where Y_{ijk} is the average production per unit area of the k^{th} crop in season j under the variety of crop i and Y_k is the total production target of crop k.

Labor requirement goal

Different levels of labor are required throughout the farming period of each crop. The number of hours of labor for each crop were expressed using Equation 3:

$$\sum_{i=1}^{n} l_{ijk}\, a_k\, x_{ijk} \leq L \quad \forall\, j,\, k \tag{3}$$

where l_{ijk} is the labor required per unit area of the k^{th} crop in season j under the variety of crop i and L is the expected total labor availability.

Water requirement goal

Water is one of the most important inputs essential for the production of crops. To meet the targeted crop production, there must be sufficient water for the farming period of every crop. The water requirement goal was expressed using Equation 4:

$$\sum_{i=1}^{I}\sum_{j=1}^{J} w_{ijk}\, a_k\, x_{ijk} \leq W \;\; \forall\, k \tag{4}$$

where w_{ijk} is the water requirement per unit area of the k^{th} crop in season j under the variety of crop i in rupees and W is the expected total water available for cultivation.

Cost of fertilizer for cultivation

Regular doses of fertilizers are required to obtain maximum profit and yield from the crop cultivation. The cost per cultivation period required for fertilizers was defined using Equation 5:

$$\sum_{i=1}^{I}\sum_{k=1}^{K} f_{ijk}\, a_k\, x_{ijk} \leq F \;\; \forall\, j \tag{5}$$

where f_{ijk} is the cost for fertilizer required per unit area of i^{th} crop in month j under variety of crop k in rupees and F is the total cost of fertilizers in Sri Lankan rupees (LKR).

Essential requirements: Land resource availability for crop cultivation

Some fixed resources are required for cultivation. Land availability is a fixed resource as it is limited for a particular study area. Thus, it can be considered as an essential requirement using Equation 6:

$$\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K} a_k\, x_{ijk} = X \tag{6}$$

where X is the total land area available for cultivation.

Fuzzy goal model structure

There are many techniques for modeling and solving optimization problems and the traditional way involves discrete deterministic analysis, where it is assumed that the parameters of the model are definitely known with no doubts about their value or occurrence. Unfortunately, this assumption is often not justified in reality. Thus, fuzzy set theory can be utilized to increase a model's realism and this can be extended to goal programing models when considering the uncertainty of parameters.

Membership function

A membership function is a generalized characteristic function of the set *X*. Membership functions are the building blocks of fuzzy set theory, with the fuzziness in a fuzzy set being determined by its membership function. The memberships can take any shape or form as long as they map the given data to an optimum consistency of membership. The decision of which membership function to use is entirely dependent on the size and the type of the problem. This study focused on the uncertainty of profit, production, labor hours, water requirement and the cost of fertilizers. To model these variables using fuzzy logic requires defining how many memberships are needed and also choosing the intervals of membership functions. Trapezoidal membership functions are more popular than triangular, trapezoidal and Gaussian membership functions in applications involving the above goals or constraints (Basumatary and Mitra, 2020). Hence, the trapezoidal membership function was used in the current study.

Trapezoidal membership function

Fig. 1A represent the shape of the trapezoidal membership function and Equation 7 represents the piece wise function:

$$\mu_{z_l}(x) = \begin{cases} 1 & , b_{l1} \le z_l(x) \le b_{l2} \\ \frac{z_l(x)-(b_{l1}-U_l^-)}{U_l^-} & , b_{l1} - U_l^- \le z_l(x) < b_{l1} \\ \frac{(b_{l2}+U_l^+)-z_l(x)}{U_l^+} & , b_l < z_l(x) \le b_{l2} + U_l^+ \\ 0 & , b_{l2} + U_l^+ < z_l(x) < b_{l1} - U_l^- \end{cases} \quad (7)$$

where $\mu_{zl}(x) \in [0,1], \forall l$ represent the membership grade of achieving the goal with 0 and 1 representing the lowest and highest grades, respectively, U_l^- is the lower tolerance limit and b_{li} is the boundary.

As most of the goals only have either a lower bound or an upper bound, the membership functions were defined as right or left trapezoidal or linear membership functions according to the goal as given below. In fuzzy goal programming, the membership function corresponding to the l^{th} fuzzy goal of type $z_l(x) \ge b_{l1}$ is defined in Equation 8 and the shape of the membership function is given in Fig. 1B.

$$\mu_{z_l}(x) = \begin{cases} 1 & , z_l(x) \ge b_{l1} \\ \frac{z_l(x)-(b_{l1}-U_l^-)}{U_l^-} & , b_{l1} - U_l^- \le z_l(x) < b_{l1} \\ 0 & , z_l(x) < b_{l1} - U_l^- \end{cases} \quad (8)$$

where $\mu_{zl}(x) \in [0,1], \forall l$ represent the membership grade of achieving the goal with 0 and 1 representing the lowest and highest grades, respectively, U_l^- is the lower tolerance limit and b_{l1} is the boundary.

Converting fuzzy goal programming model to single objective linear programming model

This conversion was required to solve and simplify the transformed fuzzy model. The steps followed in the conversion of the model are presented in Equations 9–12:

$$\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K} Y_{ijk}\, a_k\, x_{ijk} \ge \sum_{k=1}^{K} Y_k \quad (9)$$

$$\mu_{z_l}(x) \ge \lambda_l \quad (10)$$

$$\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K} Y_{ijk}\, a_k\, x_{ijk} - \lambda_l^- u_l^- \ge \sum_{k=1}^{K} Y_k - u_l^- \quad (11)$$

$$\sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K} Y_{ijk}\, a_k\, x_{ijk} + \theta_l^- u_l^- \ge \sum_{k=1}^{K} Y_k \quad (12)$$

where u_l^- is the lower tolerance and $\lambda_l^- \in [0,1]$ is the degree of satisfaction of the l^{th} goal and let $\theta_l^- = 1 - \lambda_l^-$.

The membership function corresponding to the l^{th} fuzzy goal of type $z_l(x) \le b_{l2}$ is defined in Equation 13 and the shape of the membership function is given in Fig. 1C:

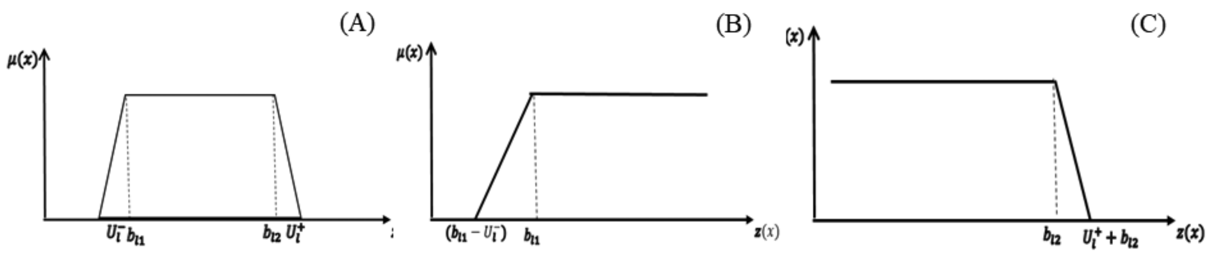

Fig. 1 Shape of membership functions: (A) trapezoidal membership function; (B) left trapezoidal membership function; (C) right trapezoidal membership function

$$\mu_{z_l}(x) = \begin{cases} 1 & , z_l(x) \le b_{l2} \\ \frac{(b_{l2}+U_l^+)-z_l(x)}{U_l^+} & , b_l < z_l(x) \le b_{l2} + U_l^+ \\ 0 & , z_l(x) > b_{l2} + U_l^+ \end{cases} \quad (13)$$

where U_l^+ is the upper tolerance limit and b_{l2} is the boundary ($b_{l1} < b_{l2}$).

Converting fuzzy goal programming model to single objective linear programming model

Similar to the above conversion, the steps followed in the conversion of the model are presented in Equations 14–17:

$$\sum_{i=1}^{n} l_{ijk}\, a_k x_{ijk} \le L \ \ , \forall\, j,\, k \quad (14)$$

$$\mu_{z_l}(x) \ \le \ \lambda_l \quad (15)$$

$$\sum_{i=1}^{n} l_{ijk} a_k\, x_{ijk} + \lambda_l^+ u_l^+ \le L + u_l^+ \ , \forall\, j,\, k \quad (16)$$

$$\sum_{i=1}^{n} l_{ijk} a_k\, x_{ijk} - \theta_l^+ u_l^+ \le L \quad (17)$$

where $\lambda_l^+ \in [0, 1]$– degree of satisfaction of the l^{th} goal and let $\theta_l^+ = 1 - \lambda_l^+$.

Formulation of objective function and final model

To define the degree of satisfaction for the model it was required to maximize the degree of satisfaction. Therefore, the fuzzy goal programming model was converted to a single objective linear programing model to maximize the degree of satisfaction; the final model is given below-:

$$\text{Minimize } \sum_{l=1}^{n} \theta_l^- + \sum_{l=n+1}^{m} \theta_l^+ \quad (18)$$

Subject to:

$$\sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{k=1}^{K} Y_{ijk}\ a_k x_{ijk} + \theta_1^- u_1^- \ge \sum_{k=1}^{K} Y_k \quad (19)$$

$$\sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{k=1}^{K} (I_{ijk} - C_{ijk}) a_k\, x_{ijk} + \theta_2^- u_2^- \ge P \quad (20)$$

$$\sum_{i=1}^{n} l_{ijk} a_k\, x_{ijk} - \theta_1^+ u_1^+ \le L \quad \forall\, j,\, k \quad (21)$$

$$\sum_{i=1}^{I} \sum_{j=1}^{J} w_{ijk}\, a_k\, x_{ijk} - \theta_2^+ u_2^+ \le W \ \ \forall\, k \quad (22)$$

$$\sum_{i=1}^{I} \sum_{k=1}^{K} f_{ijk}\, a_k\, x_{ijk} - \theta_4^+ u_4^+ \le F \quad \forall\, j \quad (23)$$

$$\sum_{i=1}^{I} \sum_{j=1}^{J} \sum_{k=1}^{K} \ a_k\, x_{ijk} = X \quad (24)$$

$$0 \le \theta_l^-, \theta_l^+ \le 1, X_{ijk} \ge 0 \quad (25)$$

$$a_k = \{0,1\} \quad (26)$$

To illustrate the application and possibility of applying the proposed fuzzy goal programming model, the following case study was conducted using the objective function in Equation 18 with the constraints in Equations 18–26.

The following stepwise algorithm can be used to illustrate the functionality of the MATLAB program for determining the optimized values of the decision variables and the accompanying objective functions:

Step 1: Identify the crops cultivated in the study area with key goals and constraints regarding their cultivation.

Step 2: Convert parameters into their equivalent deterministic form and formulate goals and constraints.

Step 3: The main function takes the user's input data and converts them into appropriate matrices. Then, these matrices are supplied as input arguments to the simplex function, which returns a single matrix with constraints and objective functions.

Step 4: Construct the membership function for each goal as mentioned in Equations 8 and 13 according to the goal maximum or minimum bound and convert to fuzzy goals.

Step 5: Introduce degree of satisfaction into each goal and goal and defuzzified fuzzy goals to linear programming problem with the objective of optimal satisfaction.

Step 6: Considering goals have the same priority in the achievement function, an equivalent fuzzy goal programming model was solved.

Application of fuzzy goal programming multi crop model in study area

This study was carried out in a farming village located in Dompe divisional secretariat in Gampaha district, Sri Lanka to optimize the land resource allocation for selected crops: brinjals (*Solanum melongena*), chilies (*Capsicum annuum*), luffa (*Luffa aegyptiaca*), wing beans (*Psophocarpus tetragonolobus*), tomatoes (*Lycopersican esculentum*), bitter gourd (*Momordica charantia*), Bird chili (*Capsicum frutescens),* Lady's fingers (*Abelmoschus esculentus*), Snake gourd (*Trichosanthes cucumerina*), manioc (*Manihot esculenta*), taro (colocasia) (*Colocasia esculenta*), rambutan (*Nephelium lappaceum*), banana (*Musa paradisicum*), pineapple (*Ananus sativus*), gadiguda (*Baccaurea metleyana*), durian fruit (*Durio*), lemon grass (*Cymbopogon*), betel (*Piper betle*), rice (*Oryza sativa*), betel nut (*Areca catechu*), coconut (*Cocos nucifera*), tea

(*Camellia sinensis*), rubber (*Hevea brasiliensis*) and pepper (*Piper nigrum*). These crops were categorized into three categories: vegetable, fruit and other. The total land area under cultivation was 47.4 ha There were six cropping seasons for the selected crops, with the number of months required for the cultivation of a particular crop defined as the season. For each crop, the season was recognized based on expert knowledge and the experience of the farmers.

Data were collected from the study area on harvest amount (measured in kilograms per square meter), land use (square meters), water consumption (cubic meters per square meter), labor requirements (hours per square meter), fertilizer cost (Sri Lankan rupees per square meter), income (Sri Lankan rupees) and costs (Sri Lankan rupees) for all crops in all seasons.

The indices are described and presented with the crops in Table 1. There were 11 vegetables, 5 fruits and 8 others. Crops were denoted as X_{ilk} where i was the variety, j was the season and k was the crop; i = 1 for vegetables, i = 2 for fruits and i = 3 for other; j = 1 defined as 2 mth period, j = 2 defined as 4 mth period, j = 3 defined as 6 mth period, j = 4 defined as 8 mth period, j = 5 defined as 12 mth period, j = 6 defined as 18 mth period and j = 7 defined as 36 mth period.

Data on available and essential resources for cultivation were collected for this study. The total land area of land under cultivation was 47.4 ha, the total availability of water was 18,390 m^3, the labor hours were 240 per month, the fertilizer costs for vegetables, fruits and other were LKR 28,366, LKR 2,9621 and LKR 27,262, respectively.

Results

Land allocations and goal achievement values corresponding to each crop index are presented in Table 2.

The optimized model suggested the maximum land allocation for rice while the minimum allocation was for rubber. The minimum coefficients of the objective function of the fuzzy goal programming model yielded the maximum membership grade for each goal. According to Fig. 2, the optimized model suggested allocating greater areas to rambutan, pineapple, gadiguda, rice, betel nut, coconut and tea compared to the existing land allocation of cultivation.

Table 1 Definitions of indices of decision variables

i	Variety of crop	j	Season (mth)	k (Crop)	X_{ijk}	Crop
1	Vegetable	1	2	1	X_{111}	Brinjal
				2	X_{112}	Chilies
				3	X_{113}	Luffa
				4	X_{114}	Winged bean
		2	4	1	X_{121}	Tomatoes
		3	6	1	X_{131}	Bitter gourd
				2	X_{132}	Bird chili
				3	X_{133}	Lady's fingers
				4	X_{134}	Snake gourd
		4	8	1	X_{141}	Manioc
		5	12	1	X_{151}	Taro
2	Fruit	4	8	1	X_{241}	Rambutan
		5	12	1	X_{251}	Banana
		6	18	1	X_{261}	Pineapple
				2	X_{262}	Gadiguda
		7	36	1	X_{271}	Durian fruit
3	Other	3	6	1	X_{331}	Lemongrass
				2	X_{332}	Betel
		4	8	1	X_{341}	Rice
		5	12	1	X_{351}	Betel nut
				2	X_{352}	Coconut
		6	18	1	X_{361}	Tea
				2	X_{362}	Rubber
		7	36	1	X_{371}	Pepper

Table 2 Allocation of land resource and coefficients of fuzzy goal model objective function

X_{ijk}	Actual (ha)	Solution (ha)	X_{ijk}	Actual (ha)	Solution (ha)
X_{111}	0.32	0.24	X_{271}	0.63	0.610
X_{112}	0.35	0.30	X_{331}	0.40	0.32
X_{113}	0.56	0.46	X_{332}	0.45	0.32
X_{114}	0.43	0.33	X_{341}	6.512	8.71
X_{121}	0.25	0.156	X_{351}	0.30	0.33
X_{131}	1.21	1.06	X_{352}	4.45	4.84
X_{132}	0.77	0.71	X_{361}	3.43	4.701
X_{133}	4.17	0.81	X_{362}	0.91	0.14
X_{134}	0.34	0.25	X_{371}	1.83	1.712
X_{141}	5.25	5.12	θ_1^-	-	0
X_{151}	1.62	1.52	θ_2^-	-	0
X_{241}	4.55	5.35	θ_1^+	-	0.3
X_{251}	0.1868	1.82	θ_2^+	-	0.4
X_{261}	6.47	7.19	θ_3^+	-	0.5
X_{262}	0.30	0.38	-	-	-

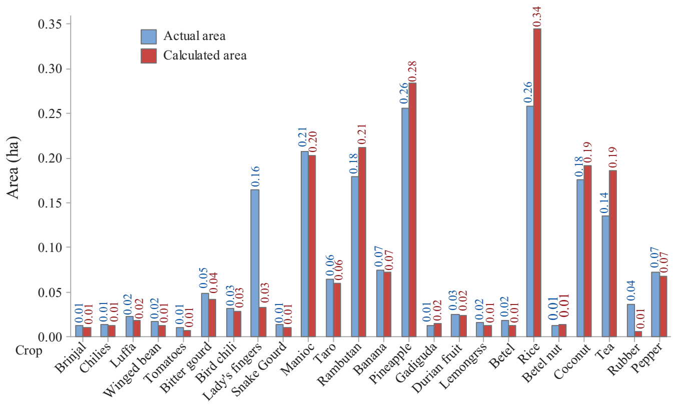

Fig. 2 Plot of actual and calculated land area of each crop

Membership functions characterize the fuzziness. Here, $\lambda_i^+ = 1 - \theta_i^+$ was defined as membership of the fuzzy model. According to Table 3, no tolerances were required for both the profit and production goals because they were completely optimized. On the other hand, for labor hours, water requirement and fertilizer cost, the required tolerances were 0.7, 0.6 and 0.5, respectively.

Fig. 3 illustrates that out of the three categories of vegetable, fruit and other, the maximum land resource was allocated for crops in the other category. Furthermore, the minimum land area was allocated to crops in the category vegetable.

The harvest amount based on the proposed model predicted a 10.6% increase from the existing cultivation production for all crops. For ease of comprehension, the results were presented for three categories (vegetable, fruit and other). Fig. 4 compares the existing and calculated harvest amounts of vegetables. According to the fuzzy goal programing model, optimal land allocation may cause some reduction in harvest amounts of vegetables as the allocated land area decreased for all vegetables.

Table 3 Membership grades and solutions

Grade of membership	λ_1^-	λ_2^-	λ_1^+	λ_2^+	λ_3^+
Solution	1	1	0.7	0.6	0.5

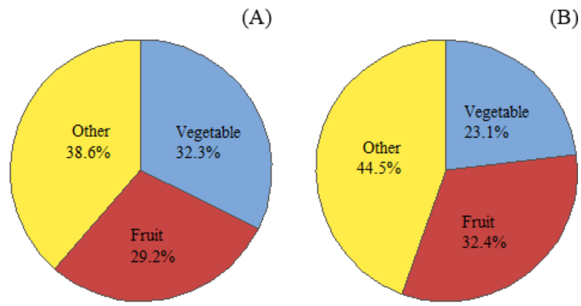

Fig. 3 Comparison of land allocation for three crop varieties: (A) actual land allocation; (B) calculated areas

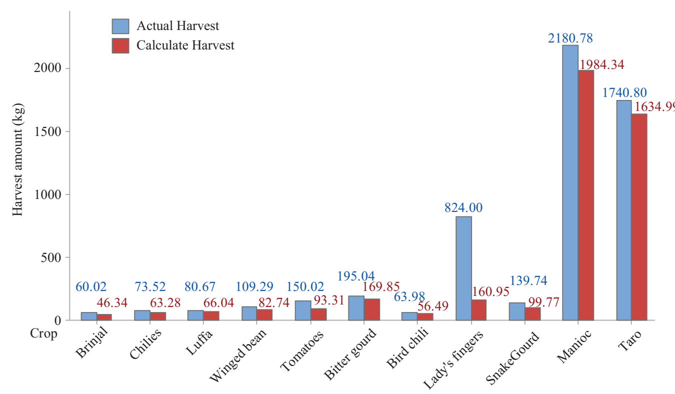

Fig. 4 Plot of actual and calculated harvest amount for vegetables

According to Fig. 5A, of the soft fruits considered in this study, the maximum harvest amount was for rambutan and pineapple. Eight varieties were considered in the other category of which the proposed model increased the harvest amounts for rice, betel nut, coconut and tea compared to the existing cultivation (Fig. 5B).

Even though it was very clear that there was increased profit from the calculated values using the fuzzy goal programming model compared to the existing cultivation, statistical analysis was applied to test for significant differences among the actual and calculated values. As, mean comparison test valid for a normally distributed data, initially test for normality. According to the results of the normality test the data set was non-normal. Transformation is one method used to covert non-normal data to normal (Feng et al., 2014). Therefore, log transformation was applied convert the normal data set with the null hypothesis (H0) being that the data follow a normal distribution and H1 being that the data do not follow a normal distribution. In these results, the null hypothesis states that the data follow a normal distribution. Because the p-value is 0.356, which is greater than the significance level of 0.05, the decision is to fail to reject the null hypothesis. Then a two sample t-test was used to determine whether there was a significant increment in profit calculated using the FGP model compared to the profit obtained from the existing cultivation based on the null hypothesis that profit calculated by the FGP model is equal to the profit obtained from the existing cultivation. The observed p-value was 0.000, which was less than 0.05, so the null hypothesis was rejected and it was concluded that the profit calculated using the FGP model was significantly higher than the profit obtained from the existing cultivation.

The selected 24 crops were categorized in to three categories (vegetable, fruit and other). The results from the two-way analysis of variance test are summarized in Table 4, with the profits obtained from both cases being significantly different at the 95% level of significance. Furthermore, comparisons between categories suggested that there were significant differences between profits obtained in two cases.

Discussion

The purpose of this study was to provide a fuzzy goal programing model for optimal allocation of the resources for various agricultural crops to maximize profit and production. The results of this study will be a useful analytical tool for agricultural officers; they can make use of linear programing and goal programing techniques to provide recommendations to farmers on the optimal allocation for different crops in the cultivation process to obtain maximum profit. The fuzzy goal programming technique described in this study for cultivation planning provides a new approach to analyze different agricultural activities in a fuzzy decision environment by considering uncertainty in real world problems (Basumatary and Mitra, 2020). The application of the fuzzy concept in cultivation planning for high economic expectations has

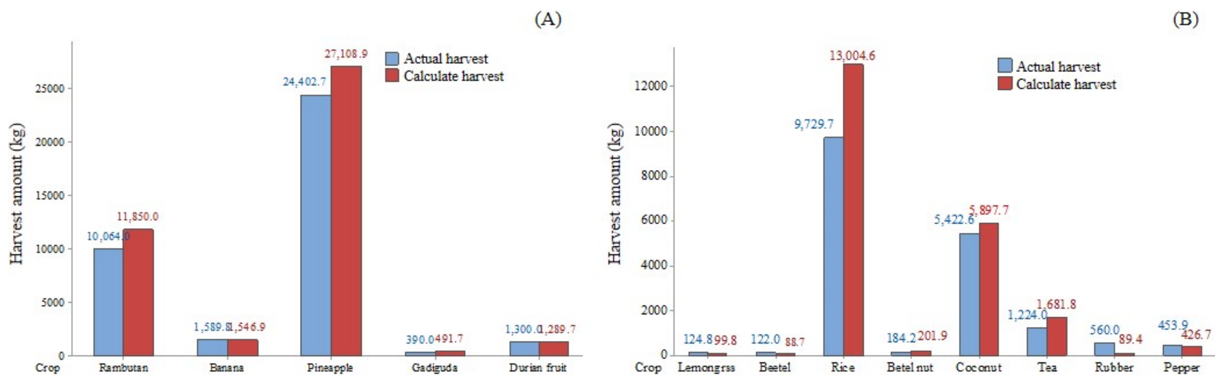

Fig. 5 Comparison of actual and calculated harvest amounts: (A) selection of fruits; (B) other crops

Table 4 Analysis of variance

Source	Level	p-value	Source	Level	p-value
Case	Actual/ existing profit	0.010	Variety	Vegetable	0.005
	Calculated profit	0.05		Fruit	0.010
				Other	0.04

successfully tackled uncertainty and imprecision in profits and harvesting (Patel et al., 2016). A fuzzy goal programming model was formulated for the optimal arable land resource allocation of 47.4 ha in the study area (Table 2). In accordance with Herath and Samarathunga (2015), land resource availability was considered as definite in nature and other objectives and constraints were considered as fuzzy. As this study considered land resource availability for crop cultivation on a fixed area, the whole arable area was allocated for crop cultivation. As a result, according to Fig. 1 the maximum land area was allocated for rice, while the minimum land area was allocated for rubber. As Table 3 illustrates, out of the five goals used in the model, the profit and production goals were completely achieved with no tolerance required, suggesting that the proposed model achieved the major objectives of maximum net return and maximum harvest from multi-crop cultivation. The fuzzy goal programming approach is a better technique than considering a single objective criterion when multiple conflicting objectives are involved (Rezayi et al., 2017). Ensuring significant saving of groundwater for different levels of groundwater availability for sustainable use of groundwater resources has been studied as one environment-friendly objective (Kaur et al., 2010). The water requirement was one of the goals in the current study. The tolerance for the water requirement goal was approximately 60% (Table 3), implying that water requirement for the proposed cultivation model was high. The labor hours required for the cultivation of the crops given in the results section varied with time. Therefore, this study considered the time component based on seasons of cultivation and the required data for this study was collected using a census conducted in the selected area. Based on the details gathered from farmers and advice from the agricultural officer in the study area, fertilizer costs were collected according to various crops. There were not good records for the use of fertilizers in the cultivation. Furthermore, conservation-minded farmers used natural waste instead of chemical fertilizers. The soil condition farmed land is one of the most important requirements for cultivation (Peltonen-Sainio et al., 2019). A limitation of the current study was that the soil condition was considered as constant across all crops and it was limited to a village located in the Dompe divisional secretariat in Gampaha district, Sri Lanka.

Successful crop cultivation for each crop requires proper planning (Shreedhar, 2018). This study proposed the optimal land allocation for fruits, vegetables and other crops, while achieving several goals as mentioned in the methodology (Fig. 3A and Fig. 3B). As a result, higher profit and harvest yields could be obtained from the proposed model compared to the existing cultivation. According to Fig. 4, the model suggested that some vegetable crops may not be providing comparable production to the other selected crops. Nevertheless, some crops in the other and fruit categories had higher production than for the existing cultivation, as presented in Figs. 5A and 5B and they should be developed and their cultivation extended under the supervision of expert agricultural officers.

Fuzzy goal programming provides a basis for handling multiple goals in land allocation problems and achieving those goals with desired targets. The decision-making process in agricultural production planning is often conducted with data that is randomly collected or not deterministic. Therefore, it is important to consider the uncertainty of the parameters in planning for cultivation. The tolerance values assigned for the fuzzy constraints can be modified according to the decision maker's preference to obtain an improved satisfactory solution. The objective of this study was to propose an optimal cultivation plan using goal programming with the fuzzy approach to allocate arable land optimally while achieving some desired goals such as maximization of profit and production. The application of the linear programming model for the same crops suggested a 5.79% increment in profit for the same study area (Hakmanage et al., 2021). However, the results of the fuzzy goal programming model suggested that an 11% increment of the net return for 24 crops could be achieved compared to the profit obtained from the existing cultivation and this was a statistically significant result (Table 4). Therefore, there was an additional nearly 5% increment of profit from the fuzzy goal model compared to the linear programming model. Optimal land allocation for fruits, vegetables and other crop varieties was proposed using the fuzzy goal programming model while achieving maximum profit from the cultivation. Furthermore, the application of the fuzzy concept in cultivation planning for high economic expectations successfully tackled the uncertainty and imprecision associated with estimating profits and production. Although the fuzzy goal programming multi-crop cultivation planning model was applied to a village in the current study, the approach could be extended to regional, state and national planning problems. The results of this study showed that the approach provides a useful statistical analytical tool for agricultural planners, allowing them to make recommendations to farmers on optimal land allocation for different crops in planning seasons to maximize profit.

Conflict of Interest

The authors declare that there are no conflicts of interest.

Acknowledgements

This research was financed by the Accelerating Higher Education Expansion and Development (AHEAD) Development Oriented Research (DOR) grant of the Ministry of Higher Education, Sri Lanka funded by the World Bank.

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