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FUZZY GOAL PROGRAMMING FOR AGRICULTURAL LAND ALLOCATION PROBLEMS

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Abstract: This paper presents a fuzzy goal programming (FGP) approach for optimal allocation of land under cultivation and proposes an annual agricultural plan for different crops. In the model formulation, goals such as crop production, net profit, water and labor requirements, and machine utilization are modeled as fuzzy. A tolerance based FGP technique is used to quantify fuzziness of different goals for the problem. The fuzzy goals are transformed to linear constraints by introducing tolerance variables. The program then minimizes the values of the weighted sum of tolerance allowance variables for the highest membership grades, providing the most satisfactory set of allocations possible. As a measure of sensitivity, the problem is solved using different weight structures specified by the decision maker. A case study is provided to illustrate the usefulness of the method.

Keywords: Fuzzy goal programming, agricultural land allocation, tolerance.

1. INTRODUCTION

Agriculture planning problems are important from both social and economic view points. They involve a complex interaction of nature and economics. Due to the increase in population, there is always a need of more production to meet the ever increasing demand. One way of achieving high productivity is to increase the area under cultivation. Third world countries like India and others are losing land due to population growth and industrialization. As a result, the production of crop per unit area must be increased by proper utilization of resources. Planning of crops is the most crucial factor of agriculture planning. Crops' planning depends on several resources like the availability of land, water, labor, and capital (Sarker and Quaddus, 2002). It also requires consideration of methods of irrigation, soil characteristics, cropping pattern, cropping intensity, topography, socio-economic conditions, climate, and many other factors. Farmers use a wide range of production systems, which result in large variations in productivity among farms. The limited availability of mathematical models to assess agriculture planners affects the development of sustainable and effective agricultural production.

During the last few decades, several operations research techniques have been used in agricultural planning. The most widely used technique in agriculture planning is linear programming (LP). LP models have been used for maximization of production of crops (Arnold and Bennet, 1975), for allocating the land under cultivation (Glen, 1987), and for minimizing cost to a farmer (Barnard and Nix, 1973). Tsai et al. (1987) used a simulation technique for optimal sequencing of a multiple cropping system. Qingzhen et al. (1991) developed an optimal production plan for crops and livestock. Some researchers have used quadratic programming (QP) techniques for agricultural planning. Takayama and Judge (1964) and Heady and Srivastava (1975) used QP to formulate the relationships between demand and prices. Simmons and Pomareda (1975), Wiens (1976), and Adams et al. (1977), and have investigated the use of QP to incorporate certain risk factors. Also, Glen (1987) has surveyed a large number of mathematical models for farm planning.

Agricultural planning problems, generally, involve multiple goals such as maximizing crop production, maximizing overall profit, minimizing labor expenditures, water requirements and others. These goals are conflicting in nature. It is not possible to maximize or minimize all goals simultaneously. Certain goals may be achieved with the expense of others. Some compromise among the goals are required to obtain a "satisfactory solution" in the decision making process. Goal programming (GP) is a useful tool for dealing problems having multiple and conflicting objective functions and for obtaining a satisfactory solution which comes closest to meeting the stated goals given the constraints of the problem. Charnes and Cooper (1961) initially proposed this technique. Later on, Lee (1972), Ignizio (1976), and others contributed significantly in the field of GP. This technique is popularly used to handle multi criteria situations within the linear programming framework. Several authors (Lee, 1972; Goodman, 1974; Romero, 1991, Sharma et al., 2003) successfully implemented the GP approach in different decision making problems.

Most of the applications in agricultural planning correspond to the problem of determining an optimum-cropping pattern with multiple goals. GP techniques have been successfully used for these purposes (Romero, 1991). Wheeler and Russell (1977) used

GP to setting goals for gross margin, seasonal cash exposure, and labor utilization and smoothing for the case of farm planting in the UK. Ghosh et al. (1993) presented the use of penalty functions in the GP model for land allocation problems for optimal production of seasonal crops. Oliveria et al. (2003) used GP for forest farm planning.

In conventional GP, parameters of the problems need to be defined precisely. In most agricultural planning problems, values of some parameters may not be known precisely. They are rather defined in a fuzzy sense. For successfully handling such problems, FGP techniques must be used. FGP has been used in agricultural planning (Slowinski, 1986; Sinha et al., 1988; Pal and Moitra, 2003; Biswas and Pal, 2005). Slowinski (1986) used FGP technique for a farm planning problem. Sinha et al., (1988), Pal and Moitra (2003) proposed FGP for agriculture planning problems. Biswas and Pal (2005) applied FGP to a land use planning problem in an agricultural system in which utilization of total cultivable land, supply of productive resources, expected profit, and expected production of various crops are defined fuzzily.

The objective of this paper is to present a tolerance based fuzzy goal programming (FGP) model for optimal allocation of land under cultivation and proposes an annual agricultural plan for different crops. The FGP technique is used to quantify fuzziness of different goals of the problem. The fuzzy goals are transformed to linear constraints by introducing tolerance variables. Minimizing the weighted sum of tolerance variables for the highest membership grades, results in the most satisfactory decision. In order to obtain all possible solutions, sensitivity analysis on different weight structures for the goals as specified by the decision maker has been performed. A case study based on data collected from the Ghaziabad district of Uttar Pradesh (India) is used to demonstrate the results.

2. THE FUZZY GOAL PROGRAMMING MODEL FORMULATION

The use of fuzzy set theory in goal programming (GP) was first introduced by Narasimhan (1980). It was further developed by Hannan (1981 & 1982), Narasimhan (1981), Ignizio (1982), Rubin and Narasimhan (1984), Tiwari et al. (1986 & 1987), Chen (1994)) and others. Chen and Tsai (2001) presented an intensive review of FGP. In this study, we have used Zimmermann’s (1985) approach to construct the membership function and Kim and Whang’s (1998) tolerance approach for the goals in a FGP for an agriculture planning problem. This approach is especially useful for FGP problems having both unequal weights and unbalanced membership values. Also, sensitivity analysis on changes to values in the model can be conducted easily because of the simplified structure of the problem.

In formulating the agricultural land allocation problem in a year, the total time period is divided into a number of seasons according to the climate conditions. Notations used to formulate the FGP model of the problem are defined next.

2.1. Notations

c: index for the crop $c \in \{1, 2,\ldots,C\}$

e: index for the essential crop $e \in \{1, 2,\ldots, E)$ and $e \in \{c\}$

s: index for the season $s \in \{1, 2,\ldots,S\}$

X_{cs}: The area of the land cultivated for crop *c* in season *s* (ha)
L_s: Total area of land for cultivation in season *s* (ha)
L_{es}: Land required cultivating for essential crop *e* in season *s* (ha)
P_{cs}: Average production per unit area of crop *c* in season *s* (qtl/ha)
TP_c: Total production target of crop *c* (qtl)
L_{cs}: Labor requirement per unit area for crop *c* in season *s* (man-days/ha)
TL: Expected labor availability in season *s* (man-days)
I_{cs}: Average investment per unit area for crop *c* in season *s* (Rs./ha/season)
TI: Total investment available in season *s* (Rs.)
M_{cs}: Annual machine-hours per unit area for crop *c* in season *s* (hrs/ha)
TM: Expected total machine-hours available in season *s* (hrs)
N_{cs}: Net profit for crop *c* in season *s* (Rs./qtl)
N: Expected net profit for all crops (Rs.)
C_s: Total number of crops cultivated in season *s*
W_{cs}: Amount of water requirements for the crop *c* in season *s* (cubic cm/ha)
W_s: Expected total ground water available for irrigation in season *s* (cubic cm)

2.2. The Goals

The goals for the FGP problem may be defined as follows:
(i) **Crop production goal:** The decision maker will try to maximize expected crop production. This is obtained by multiplication of the area estimate with the corresponding yield estimates in that season. The sum of the productions for all the crops should be greater or equal to the expected production target during the year. The goal equation for crop production can be expressed as

$$\sum_{s=1}^{S} \sum_{c=1}^{C} P_{cs} X_{cs} \underset{\sim}{>} \sum_{c=1}^{C} TP_c \tag{2.1}$$

(ii) **Net profit goal**: The decision maker will require a certain level of profit from the crops. The goal equation for net profit can be expressed as

$$\sum_{s=1}^{S} \sum_{c=1}^{C} N_{cs} X_{cs} \underset{\sim}{>} N \tag{2.2}$$

(iii) **Labor requirement goal**: The farm will hire an estimated number of agricultural laborers throughout the year. The goal equation for laborers can be written as

$$\sum_{s=1}^{S} \sum_{c=1}^{C} L_{cs} X_{cs} \underset{\sim}{<} TL \tag{2.3}$$

(iv) **Water requirement goal:** To meet the production target of each crop in a year, adequate water supply must be ensured. The goal equation for water supply can be written as

$$\sum_{c=1}^{C} W_{cs} X_{cs} \underset{\sim}{<} W_s, \quad \forall s \tag{2.4}$$

(v) **Machine utilization goal:** For tilling the land throughout the year, there is an annual machine-hour estimate. The machine-hours allocated to each season should not exceed the machine-hours available in each season. The goal equation for annual machine-hours can be expressed as

$$\sum_{s=1}^{S}\sum_{c=1}^{C} M_{cs} X_{cs} \underset{\sim}{<} TM \tag{2.5}$$

2.3. Essential requirements

The farm has fixed resources like available land for cultivation and available budget to meet different essential requirements. Also, to meet the community's food requirement some fixed area of land must be kept for essential crops. To satisfy these essential requirements, the following constraints must be satisfied in the FGP model.

(i) **Cultivable land availability**: Each crop occupies land according to its crop season. The sum of available land for all crops must not exceed total cultivable land available in the season. The goal equation for cultivable land availability can be expressed as

$$\sum_{c=1}^{C} X_{cs} \le L_s, \quad \forall s \tag{2.6}$$

(ii) **Food requirement**: To meet the community's food requirement, some area of land should be kept for essential crop(s) in the season. The goal equations for land available for essential crop(s) can be written as

$$X_{es} \le L_{es}, \quad \forall s \tag{2.7}$$

and

$$\sum_{e=1}^{E} L_{es} \le L_s \text{ , } e \in \{1, 2, ..., C\}, \quad \forall s \tag{2.8}$$

(iii) **Working capital requirement:** A set amount of money per year must be reserved for fertilizers, seeds, machinery maintenance and insecticides, etc. The goal equation for this working capital can be written as

$$\sum_{s=1}^{S}\sum_{c=1}^{C} I_{cs} X_{cs} \le TI \tag{2.9}$$

2.4. Transformation of fuzzy goals

In fuzzy goal programming, the membership function corresponding to the k -th fuzzy goal of type $z_k(x) \underset{\sim}{>} b_k$ is defined as

$$\mu_{z_k}(x) = \begin{cases} 1 & if \quad z_k(x) \ge b_k \\ \dfrac{z_k(x) - (b_k - t_k^l)}{t_k^l} & if \quad b_k - t_k^l \le z_k(x) < b_k \\ 0 & if \quad z_k(x) < b_k - t_k^l \end{cases}$$

where t_k^l is the lower tolerance limit and corresponding to the k-th fuzzy goal of type $z_k(x) \underset{\sim}{<} b_k$, and is defined as

$$\mu_{z_k}(x) = \begin{cases} 1 & if \quad z_k(x) \le b_k \\ \dfrac{(b_k + t_k^u) - z_k(x)}{t_k^u} & if \quad b_k < z_k(x) \le b_k + t_k^u \\ 0 & if \quad z_k(x) > b_k + t_k^u \end{cases}$$

where t_k^u is the upper tolerance limit.

$\mu_{z_k}(x) \in [0,1], \forall k$ represents the membership grade of achieving the goal with 0 and 1 representing the lowest and highest grade, respectively. The membership grade depends on the specified tolerance value given in the decision making context.

In the considered FGP model of the agricultural land allocation problem, the crop production goal (2.1) and the net profit goal (2.2) are of type $z_k(x) \underset{\sim}{>} b_k$. On the other hand, labor requirements (2.3), water requirements (2.4) and machine utilization (2.5) goals are of type $z_k(x) \underset{\sim}{<} b_k$. If crop production and net profit goals are completely achieved then no tolerances for them are needed and the grades of membership for the goals should be unity. When these goals are either perfectly or partially unachieved, tolerances for them are required. Kim and Whang (1998) used the concept of tolerance to convert an FGP model to a single objective LP problem. If $u_i^-, i = 1,2$ are the lower tolerances and $\lambda_i^- \in [0,1], i = 1,2$ are the grades of membership, then the corresponding crop production and net profit goals can be transformed as:

$$\sum_{s=1}^{S} \sum_{c=1}^{C} P_{cs} X_{cs} - \lambda_1^- u_1^- \ge \sum_{c=1}^{C} TP_c - u_1^-$$

i.e., $$\sum_{s=1}^{S} \sum_{c=1}^{C} P_{cs} X_{cs} + \theta_1^- u_1^- \ge \sum_{c=1}^{C} TP_c$$

and $$\sum_{s=1}^{S} \sum_{c=1}^{C} N_{cs} X_{cs} + \theta_2^- u_2^- \ge N$$

where $\theta_i^- = 1 - \lambda_i^-, i = 1,2$.

If u_1^+ is the upper tolerance limit and λ_1^+ is the membership grade of labor requirement goal, then proceeding in a similar manner, the goal can be transformed as follows:

$$\sum_{s=1}^{S} \sum_{c=1}^{C} L_{cs} X_{cs} - \theta_1^+ u_1^+ \le TL$$

where $\theta_1^+ = 1 - \lambda_1^+$.

The water requirement goal can be transformed as

$$\sum_{c=1}^{C} W_{cs} X_{cs} - \theta_{2,s}^{+} u_{2,s}^{+} \le W_s, \quad \forall s$$

where $\theta_{2,s}^{+} = 1 - \lambda_{2,s}^{+}$, $u_{2,s}^{+}$ is the upper tolerance limits and $\lambda_{2,s}^{+}$ is the membership grades of water requirement goals in season s.

Finally, the machine utilization goal can be transformed as

$$\sum_{s=1}^{S} \sum_{c=1}^{C} M_{cs} X_{cs} - \theta_3^{+} u_3^{+} \le TM$$

where $\theta_3^{+} = 1 - \lambda_3^{+}$, u_3^{+} is the upper tolerance limit and λ_3^{+} is the membership grade of labor requirement goal.

2.5. Formulation of objective function

The fuzzy goals for the problem are transformed to their respective linear constraint form. In this formulation, as the tolerance variables are to be minimized, the tolerances be needed will be close to unity for each fuzzy goal. This causes the grade of membership to become larger. In particular, if the tolerance variables are zero then there is no need to assign tolerances to fuzzy goals. Therefore, the objective function for the agricultural land allocation problem is defined as (Kim and Whang, 1998)

$$\min: \sum_{i=1}^{2} w_i \theta_i^{-} + \sum_{i=3}^{4} w_i \theta_i^{+} + \sum_{s=1}^{S} w_{2,s} \theta_{2,s}^{+}$$

where $w_i, i = 1,2,3,4$ and $w_{2,s}, \forall s$ are the respective weights corresponding to the fuzzy goals and the sum of all weights is one.

2.6. Final form

The final LP form of the agricultural land allocation problem is obtained as follows:

$$\min: \sum_{i=1}^{2} w_i \theta_i^{-} + \sum_{i=3}^{4} w_i \theta_i^{+} + \sum_{s=1}^{S} w_{2,s} \theta_{2,s}^{+} \tag{2.10}$$

subject to

$$\sum_{s=1}^{S} \sum_{c=1}^{C} P_{cs} X_{cs} + \theta_1^{-} u_1^{-} \ge \sum_{c=1}^{C} TP_c \tag{2.11}$$

$$\sum_{s=1}^{S} \sum_{c=1}^{C} N_{cs} X_{cs} + \theta_2^{-} u_2^{-} \ge N \tag{2.12}$$

$$\sum_{s=1}^{S} \sum_{c=1}^{C} L_{cs} X_{cs} - \theta_1^{+} u_1^{+} \le TL \tag{2.13}$$

$$\sum_{c=1}^{C} W_{cs} X_{cs} - \theta_{2,s}^{+} u_{2,s}^{+} \le W_s, \quad \forall s \tag{2.14}$$

$$\sum_{s=1}^{S} \sum_{c=1}^{C} M_{cs} X_{cs} - \theta_3^{+} u_3^{+} \le TM \tag{2.15}$$

$$\sum_{c=1}^{C} X_{cs} \le L_s, \quad \forall s \tag{2.16}$$

$$X_{es} \le L_{es}, \quad \forall s \tag{2.17}$$

$$\sum_{e=1}^{E} L_{es} \le L_s, \; e \in \{1, 2, ..., C\}, \quad \forall s \tag{2.18}$$

$$\sum_{s=1}^{S} \sum_{c=1}^{C} I_{cs} X_{cs} \le TI \tag{2.19}$$

$$0 \le \theta_1^{-}, \theta_2^{-}, \theta_1^{+}, \theta_2^{+}, \theta_{2,s}^{+} \le 1, \quad \forall s \tag{2.20}$$

$$\sum_{i=1}^{4} w_i + \sum_{s=1}^{S} w_{2,s} = 1 \tag{2.21}$$

$$X_{cs} \ge 0 \tag{2.22}$$

To demonstrate the usefulness of the proposed FGP model, the following case study has been considered.

3. A CASE STUDY

The Ghaziabad district of Uttar Pradesh (India) is taken as the study region to illustrate the model. The district consists of 1133 villages and its geographical area is 2470 sq. km. The majority of the population depends on agriculture. The data regarding the production of crops (qtl/ha), land use (ha), water consumption (cubic cm/ha), requirement of labor (man-days/ha), requirement of machinery (hrs./ha), and cash (Rs.) requirement for all crops throughout the year have been collected from the various sources such as the Statistical Department of the Ghaziabad district, yearly agricultural development program and personal surveys with the farmers.

The crops are denoted as c=1 for cane, c=2 for wheat, c=3 for rice, c = 4 for maize, c=5 for potatoes, c=6 for tilhan, c=7 for cotton, c=8 for pulses, c=9 for barley, c=10 for jowar, c=11 for millet. The 1st cropping season, s=1, is defined as the period June to November and the 2nd season (s=2) is defined as the period December to May. The total area of land under cultivation is 170638 ha. For both seasons, the required data are summarized in the following tables.

Table 1: Goal Description

Goal	Target	Tolerance
1. Production (‘000 qtl)	64176	9040
2. Net profit (Rs. ‘000)	8000000	1000000
3. Labor requirement (‘000 man-days)	86403	12000
4. Machine utilization (‘000 hrs)	2528	650
5. Water requirement (‘000 cubic cm.)		
(i) Season 1	9280	1000
(ii) Season 2	3756	600

Table 2: Data Description

Crops	M_{cs} (hrs/ha)	L_{cs} (man-days/ha)	W_{cs} (cubic cm/ha)	P_{cs} (qtl/ha)	I_{cs} (Rs.)	N_{cs} (Rs./ha)
Season 1						
Cane	5.18	320	110	601.40	8828.00	40500.00
Rice	8.15	350	18	21.36	7647.08	23212.01
Season 2						
Wheat	5.18	180	40	33.03	4026.40	21604.84
Rice	8.15	285	11	15.59	5410.00	28847.20
Maize	8.12	300	40	14.55	4900.53	18119.62
Potato	12.25	125	20	369.10	7587.63	55945.03
Tilhan	5.20	95	20	11.12	5005.07	30110.80
Cotton	5.25	210	30	2.08	3195.43	42050.40
Pulses	5.20	60	20	7.12	2891.85	14716.03
Barley	5.18	95	40	33.39	2925.40	15886.90
Jowar	5.16	85	40	7.51	3650.40	120183.10
Millet	5.16	90	40	15.08	3469.70	210519.30

Source: Sankhyakiya Patrika, District Ghaziabad, pp. 9-11, 2005.

Table 3: Variables of the Model

X_{11}	Cane in season 1	X_{12}	Rice in season 1
X_{21}	Wheat in season 2	X_{22}	Rice in season 2
X_{23}	Maize in season 2	X_{24}	Potato in season 2
X_{25}	Tilhan in season 2	X_{26}	Cotton in season 2
X_{27}	Pulses in season 2	X_{28}	Barley in season 2
X_{29}	Jowar in season 2	$X_{2,10}$	Millet in season 2
λ_1^-	Membership grade for production goal	λ_2^-	Membership grade for profit goal
λ_1^+	Membership grade for labor goal	λ_3^+	Membership grade for machine goal
$\lambda_{2,1}^+$	Membership grade for water goal in season 1	$\lambda_{2,2}^+$	Membership grade for water goal in season 2

4. RESULTS

The model is formulated using the above data and is executed using LINGO 10.0. Land allocations and goal achievement values corresponding to two different weighting structures are presented in Table 4.

Table 4: Membership Grades & Land Allocation ('000 ha)

Variables	Land Allocation		
	Equal Weights	Weights (0.4, 0.2, 0.1, 0.2, 0.05, 0.05)	Weights (0.2, 0.3, 0.2, 0.1, 0.1, 0.1)
λ_1^-	0.9465	1.0000	1.0000
λ_2^-	1.0000	1.0000	1.0000
λ_1^+	0.9805	1.0000	1.0000
λ_3^+	0.9207	0.9279	0.9186
$\lambda_{2,1}^+$	1.0000	0.9635	1.0000
$\lambda_{2,2}^+$	0.8914	0.8340	0.8105
X_{11}	67.4839	67.8802	67.4839
X_{12}	103.1541	102.7578	103.1541
X_{21}	30.000	30.0000	30.0000
X_{22}	45.7418	43.5635	42.9009
X_{23}	3.1200	3.1200	3.1200
X_{24}	50.8931	51.5874	52.2585
X_{25}	15.0000	15.0000	14.1752
X_{26}	0.0000	1.4841	2.3003
X_{27}	18.0001	18.0000	18.0000
X_{28}	0.0000	0.0000	0.0000
X_{29}	2.0100	2.0100	2.0100
$X_{2,10}$	5.8730	5.8730	5.8731

In the case of equal weights, the above results indicate that no tolerances are required for profit and water requirements in the season 1 goals because they are achieved completely. On the other hand, for production, labor, machine utilization, and water requirements in the season 2 goals, the required tolerances are 0.0535, 0.0195, 0.0793, and 0.1086 respectively. Similarly, for the weighting structure (0.4, 0.2, 0.1, 0.2, 0.05, 0.05), the production, profit and labor requirement goals are achieved completely and tolerance values for machine utilization and water requirement in season 1 and 2 goals are 0.0721, 0.0365 and 0.1660 respectively. Also, for the weighting structure (0.2, 0.3, 0.2, 0.1, 0.1, 0.1), the production, profit, labor and water requirements in season 1 goals are achieved completely and tolerance values for machine utilization and water requirement in season 2 goals are 0.0813 and 0.1895 respectively.

5. CONCLUSION

The objective of this study is to present a FGP model for optimal allocation of land under cultivation and proposes an annual agricultural plan for different crops. The output of our research may become a useful analytical tool for agricultural planners, who are using traditional LP and GP methods for recommendations to the farmer on optimal land allocation for different crops in the planning process. In this study, we have been able to demonstrate that the FGP approach is a better technique over a single objective criterion when multiple conflicting objectives are involved. The model developed provides the best possible solution subject to the model constraints. Sensitivity analysis considering two different weighting structures of the goals has been performed to see the adaptability of the proposed model. Results may be tested and verified corresponding to other weighting structures specified by the decision maker depending on the agricultural planning situation.

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