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Application of fuzzy goal programming technique to land use planning in agricultural system

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Abstract

This paper presents how fuzzy goal programming can be efficiently used for modelling and solving land-use planning problems in agricultural systems for optimal production of several seasonal crops in a planning year. In the model formulation of the problem, utilization of total cultivable land, supply of productive resources, aspiration levels of various production of crops as well as the total expected profit from the farm are fuzzily described. In the decision-making situation, minimization of the under-deviational variables of the membership goals with highest membership value (unity) as their achievement levels defined for the membership functions of the fuzzy goals of the problem on the basis of the priorities of importance of achieving the aspired levels of the fuzzy goals to the extent possible is considered. As a study region, the District Nadia, West Bengal, India is taken into account. To expound the potential use of the approach, the model solution is compared with the existing cropping plan of the District as well as a solution of the problem obtained by using the additive fuzzy goal programming model studied by Tiwari et al. (Fuzzy sets and systems 24(1987)27.) previously.

Keywords: Linear programming; Fuzzy linear programming; Goal programming; Fuzzy goal programming; Land-use planning

1. Introduction

Mathematical programming models for agricultural planning problems have been widely used since Heady [1] demonstrated the use of linear programming (LP) for land allocation to crop planning problems.

From 1960s to mid-1980s, LP models of different farm planning problems have been extensively studied [2–5]. The potential use of LP for agricultural planning problems has been surveyed by Glen [6] in 1987.

Since LP is a single objective optimization technique and most of the farm planning problems are multiobjective in nature, the goal programming (GP) [7] approach, one of the prominent tools for multiobjective decision analysis, to land allocation planning problem for optimal production of several crops was first introduced by Wheeler and Russel [8] in 1977. The application potential of GP to farm planning problems has been surveyed by Romero [9]. The use of preemptive priority based GP to land-use planning problem has also been discussed by Pal and Basu [10].

Although GP has been widely used to farm planning problems, the main weakness of conventional GP formulation is that all the parameters of the problem need to be specified precisely in the planning environment. But, in most of the practical decision problems, they are often imprecisely defined due to the expert's ambiguous understanding of the nature of them. So, assigning of definite aspiration levels to the goals of the problem frequently creates decision trouble in most of the farm planning situations.

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To overcome the above difficulty, the concept of fuzzy sets, initially proposed by Zadeh [11], has been introduced to the field of multiobjective optimization problems [12]. The use of fuzzy linear programming (FLP) to farm planning problems has been discussed by Slowinski [13]. The fuzzy goal programming (FGP) approach [14] to crop planning problems in the environment of crisp resource constraints has been recently studied by Pal and Moitra [15]. However in contrast to LP and GP approaches, fuzzy programming (FP) approach to farm planning problems has not been appeared extensively in the literature.

In this paper, a priority-based FGP formulation for optimal production of seasonal crops by utilizing the cultivable land and the available productive resources is presented. In the solution process, the sensitivity analysis with the variations of priority structure of the goals is performed to present how the solution is sensitive to the change in priority structure. Then the *Euclidean distance function* is used to identify the appropriate priority structure under which the most satisfactory decision for the cropping plan can be reached in the decision-making environment.

2. FGP problem formulation

In a fuzzy decision-making environment, the objectives of the decision maker (DM) are always described fuzzily. Again, the resource constraints may be crisp or fuzzy and that depends on the fuzziness of the available resources in the planning context.

Let b_k be the aspiration level of the kth objective $F_k(X)$ $(k = 1, 2, \ldots, K)$. Then the fuzzy goals may appear in one of the forms

$$F_k(X) \gtrsim b_k \quad \text{and} \quad F_k(X) \lesssim b_k,$$

where X is the vector of decision variables, and where $\gtrsim$ and $\lesssim$ indicate the fuzziness of $\geqslant$ and $\leqslant$ restrictions, respectively, in the sense of Zimmermann [16].

2.1. Construction of membership function

In a fuzzy decision-making situation, the fuzzy goals are characterized by their membership functions by defining the lower or upper tolerance limit, and that depends on the fuzzy restriction given to a fuzzy goal of the problem.

Let t_{lk} and t_{uk} be the lower- and upper-tolerance ranges, respectively, for achievement of the aspired level b_k of the kth fuzzy goal. Then, the membership function, say $\mu_k(X)$, for the fuzzy goal $F_k(X)$ can be characterized as follows [17]:

For $\gtrsim$ type of restriction, $\mu_k(X)$ takes the form

$$\mu_k(X) = \begin{cases} 1 & \text{if } F_k(X) \geqslant b_k, \\ \frac{F_k(X) - (b_k - t_{lk})}{t_{lk}} & \text{if } b_k - t_l k \leqslant F_k(X) < b_k, \\ 0 & \text{if } F_k(X) < b_k - t_{lk}, \end{cases} \tag{2.1}$$

where $(b_k - t_{lk})$ represents the lower-tolerance limit for achievement of the stated fuzzy goal. Again, for $\lesssim$ type of restriction, $\mu_k(X)$ becomes

$$\mu_k(X) = \begin{cases} 1 & \text{if } F_k(X) \leqslant b_k, \\ \frac{(b_k + t_{uk}) - F_k(X)}{t_{uk}} & \text{if } b_k < F_k(X) \leqslant b_k + t_{uk}, \\ 0 & \text{if } F_k(X) > b_k + t_{uk}, \end{cases} \tag{2.2}$$

where $(b_k + t_{uk})$ represents the upper-tolerance limit for achievement of the stated fuzzy goal. It may be mentioned here that if the resource constraints are also considered as fuzzy, then the membership functions for them can be defined in an analogous to the above expressions in (2.1) and (2.2).

2.2. FGP formulation

In FGP formulation, the membership functions are transformed into membership goals by assigning the highest degree (unity) as the aspiration level and introducing under- and over-deviational variables to each of them. Then, in the goal achievement function, the under-deviational variables are minimized on the basis of importance of achieving the aspired goal levels in the decision-making context.

The FGP model of the problem under a pre-emptive priority structure can be presented as:

Find X so as to

Minimize $Z = [P_1(d^-), P_2(d^-), \ldots, P_i(d^-), \ldots, P_I(d^-)]$

and satisfy

$$\frac{F_k(X) - (b_k - t_{lk})}{t_{lk}} + d_k^- - d_k^+ = 1$$

$$\frac{(b_k + t_{uk}) - F_k(X)}{t_{uk}} + d_k^- - d_k^+ = 1$$

$$d_k^-, d_k^+ \geqslant 0 \quad k = 1, 2, \ldots, K, \tag{2.3}$$

where Z represents the vector of I priority achievement functions and d_k^-, d_k^+ are the under- and over-deviational variables of the kth goal. $P_i(d^-)$ is a linear function of the weighted under-deviational variables, where $P_i(d^-)$ is of the form

$$P_i(d^-) = \sum_{k=1}^{K} w_{ik}^- d_{ik}^-; \; w_{ik}^-, d_{ik}^- \geqslant 0,$$
$$(k = 1, 2, \ldots, K; \; I \leqslant K),$$

where d_{ik}^- is renamed for d_k^- to represent it at the ith priority level, w_{ik}^- is the numerical weight associated with d_{ik}^- and represents the weight of importance of achieving the aspired level of the kth goal relative to others which are grouped together at the ith priority level. The w_{ik}^- values are determined as [17]:

$$w_{ik}^- = \begin{cases} \frac{1}{(t_{lk})_i} & \text{for the defined } \mu_k(X) \text{ in (2.1)}, \\ \frac{1}{(t_{uk})_i} & \text{for the defined } \mu_k(X) \text{ in (2.2)}, \end{cases} \tag{2.4}$$

where $(t_{lk})_i$ and $(t_{uk})_i$ are used to represent t_{lk} and t_{uk}, respectively, at the ith priority level.

It is worthy to mention here that the notion of preemptive priorities of the goals actually holds that the ith priority P_i is preferred to the next priority P_{i+1} regardless of any multiplier associated with P_{i+1}. Also, the relationship among the priorities are

$$P_1 >>> P_2 >>> \cdots >>> P_i >>> \cdots >>> P_I,$$

which implies that the goals at the highest priority level (P_1) are achieved to the extent possible before the set of goals at the second priority level (P_2) is considered and so forth.

2.3. Priority selection technique: use of Euclidean Distance Function

In the context of assigning priorities to the goals in the above FGP formulation, it may be mentioned here that the DM is always confused with that of assigning the proper priorities to the goals, because the goals often conflict among themselves for achieving their aspired levels in the decision making environment. To overcome such a situation, the concept of using *Euclidean Distance Function* for group-decision analysis introduced by Yu [18] can be used for measuring the ideal point dependent solution and then identifying the appropriate priority structure of the goals under which the most satisfactory decision is reached.

In the present decision situation, since the highest membership value of each fuzzy goal is 1, the ideal point would be a vector with each element equal to 1.

The *Euclidean Distance Function* can be represented as

$$D_j = \left[\sum_{k=1}^{K} (1 - \mu_k^j)^2 \right]^{1/2},$$

where μ_k^j represents the achieved membership value of the kth goal under the jth priority structure of the goal.

Here, it can be realized that the solution which is closest to the ideal point must correspond to

$$j = \min_{1,2,\ldots,J} \{D_j\} = D_m (\text{say}), \quad 1 \leqslant m \leqslant J.$$

Then, mth priority structure would be considered as an appropriate one to arrive at the most satisfactory decision.

Now, in the present FGP formulation of the problem, the objectives as well as the productive resources are considered as fuzzy in the decision-making environment.

The decision variables and different types of parameters used in the formulated model are presented in the following Section 2.4.

2.4. Definitions of variable and parameters

Decision variable:
x_{cs} = allocation of the land for cultivating the crop c during the season s
Fuzzy productive resources:
L_s = total area of land (in hectares (ha)) currently in use for cultivating the crop in the season s
M_h = estimated total machine hours (in hrs.) required during the year.
M_d = estimated total mandays (in days) required during the year
W_s = estimated total amount of water (in ha/inch) required during the season s
T_f = estimated total amount of the fertilizer $f(f = 1, 2, \ldots, \mathrm{F}_1)$ (in quintals (qtls.)) required during the year
C_r = estimated total amount of cash (in Rupees (Rs.)) required per annum for supply of the productive resources
P_c = annual production level (in qtls.) of the crop c
M_p = estimated total market value (in Rs.) of all the yielding crops in different seasons in a year
Crisp coefficients:
MH_{cs} = average machine hours (in hrs.) required for tillage per ha of land for cultivating the crop c during the season s
MD_{cs} = mandays (in days) required per ha of land for cultivating the crop c during the season s
W_{cs} = amount of water consumed (in inch) per ha of land for cultivating the crop c during the season s
F_{fcs} = amount of the fertilizer f required per ha of land for cultivating the crop c during the season s
P_{cs} = estimated production of the crop c per ha of land cultivated during the season s.
MP_{cs} = market price (Rs./qtl.) at the time of harvest of the crop c cultivated during the season s

Fuzzy goal description:

The fuzzy goals of the formulated model are as follows:
1. *Land utilization goal*:
The fuzzy goals for utilization of total cultivable land in different seasons take the forms
$\sum_{c=1}^{C} x_{cs} \lesssim L_s, \quad s = 1, 2, \ldots, S.$
2. *Productive resource goals*:
(a) *Machine-hour goal*:
An estimated number of machine hours is to be provided to till the land in different seasons of the year.
The fuzzy goal appear as:
$\sum_{s=1}^{S} \sum_{c=1}^{C} x_{cs} \mathrm{MH}_{cs} \gtrsim M_h.$
(b) *Man-power requirement goal*:
A number of labourers are to be employed through out the year to avoid the trouble with hiring of more labourers at the peak times and involvement of extra cost for it.
The fuzzy goal takes the form:
$\sum_{S=1}^{s} \sum_{c=1}^{C} x_{cs} \mathrm{MD}_{cs} \gtrsim M_d.$

(c) *Water consumption goal*:
Water is an essential input for yielding the crops. So, a minimum supply level of water is needed in each cropping season.
The fuzzy goals appear as
$\sum_{c=1}^{C} x_{cs} W_{cs} \gtrsim W_s, \quad s = 1, 2, \ldots, S.$
(d) *Fertilizer requirement goal*:
To maintain the productivity of the soil, different types of fertilizers are to be used in different seasons in the year.
The fuzzy goals appear as
$\sum_{s=1}^{S} \sum_{c=1}^{C} x_{cs} F_{fcs} \gtrsim T_f, \quad f = 1, 2, \ldots, F_1.$
3. *Cash expenditure goal*:
An estimated amount of cash (Rs.) is involved for the purpose of purchasing the seeds, fertilizers and other productive resources.
The fuzzy goal takes the form
$\sum_{s=1}^{S} \sum_{c=1}^{C} x_{cs} A_{cs} \lesssim C_r.$
4. *Production achievement goal*:
To meet the demand of agricultural products in society, a minimum achievement level of production of each type of the crops is needed.
The fuzzy goal appears as
$\sum_{s=1}^{S} x_{cs} P_{cs} \gtrsim P_c, \quad c = 1, 2, \ldots, C.$
5. *Profit goal*:
A certain level of profit from the farm is highly expected by the farm manager.
The fuzzy profit goal appears as
$\sum_{s=1}^{S} \sum_{c=1}^{C} (MP_{cs} P_{cs}) x_{cs} \gtrsim M_p.$
Now, construction of membership functions for the defined fuzzy goals and then the FGP formulation of the problem are demonstrated through the following case example.

3. An illustrative case example

The land-use planning problem for production of the principal crops of the Nadia District in West Bengal, INDIA is considered to illustrate the proposed FGP model. The data of the planning year 1999–2000 (publication year 2001) were collected from different agricultural planning units. The sources are: District Statistical Hand Book, Nadia, 1999–2000 [19], Action Plan Records (2000–2001 and 1999–2000) [20], Department of Agricultural Marketing [21], G. O. No. 6533 / 2 (376) M. I.- I Branch, Government (Govt.) West Bengal (W. B.), [22], Soil Testing and Fertilizer Recommendation [23]. The Murshidabad Central Cooperative Bank Ltd. [24], Department of Agri-Irrigation [25], Economic Review [26].

The different types of seasonal crops and the decision variables representing them in the formulated model are given in Table 1.

The data for the aspiration levels of the fuzzy goals and their respective tolerance limits are presented in Table 2.

The data description for productive resource utilization, production rate and market price are given in Table 3.

Table 1
Summary of the seasonal crops and the associated decision variables

Season (s)	Crop (c)	Variable (x_{cs})
Prekharif (1)	Jute (1)	x_{11}
	Sugarcane (2)	x_{21}
	Aus (3)	x_{31}
Kharif (2)	Aman (4)	x_{42}
Rabi (3)	Boro (5)	x_{53}
	Wheat (6)	x_{63}
	Mustard (7)	x_{73}
	Potato (8)	x_{83}

Now, using the data in Table 2 and 3, the membership functions for the defined fuzzy goals can be constructed by (2.1) and (2.2). Here, the fuzzy goals for utilization of land in the Prekharif season takes the form:

$$x_{11} + x_{21} + x_{31} \lesssim 272.135.$$

Then, for the given upper tolerance limit of the cultivable land, the membership function for the stated fuzzy goal appear as

$$\mu_1 = \frac{309.33 - (x_{11} + x_{21} + x_{31})}{37.195}.$$

In the same way, the membership functions for the other fuzzy goals of the model can be determined. Then, the membership goals for the defined membership functions are obtained as follows:

1. *Land utilization goals*: It may be noted here that most of the crops are single-season based, but three consecutive seasons are required for yielding the crop sugarcane.

The membership goals for utilization of land in the three successive seasons appear as

$$\text{(i)}\quad \mu_1 : 8.316 - 0.027(x_{11} + x_{21} + x_{31}) + d_1^- - d_1^+ = 1,$$
$$\text{(ii)}\quad \mu_2 : 8.316 - 0.027(x_{21} + x_{42}) + d_2^- - d_2^+ = 1,$$
$$\text{(iii)}\quad \mu_3 : 8.316 - 0.027(x_{21} + x_{53} + x_{63} + x_{73} + x_{83}) + d_3^- - d_3^+ = 1.$$

2. *Productive resource goals*:

(a) Machine-hour goal:

$$\mu_4 : 0.008(x_{11} + x_{21} + x_{31}) + 0.005x_{42} + 0.005x_{53} + 0.005(x_{63} + x_{73} + x_{83}) - 3.772 + d_4^- - d_4^+ = 1.$$

(b) Man power goal:

$$\mu_5 : 0.043x_{11} + 0.085x_{21} + 0.029x_{31} + 0.031x_{42} + 0.038x_{53} + 0.025x_{63} + 0.016x_{73} + 0.041x_{83} - 14.958 + d_5^- - d_5^+ = 1.$$

Table 2
Data description for the fuzzy goals

	Goal	Aspiration level	Tolerance limit	
			Lower	Upper
1.	Land utilization (in ’000 hectares)			
	(i) Prekharif season	272.135	—	309.33
	(ii) Kharif season	272.135	—	309.33
	(iii) Rabi season	272.135	—	309.33
2.	(a) Machine-hour (in hours)	37,843.75	29,912.80	—
	(b) Man-days (in days)	46,510.66	43,596.18	—
	(c) Water consumption (in inch) :			
	(i) Prekharif season	2727.84	2524.34	—
	(ii) Kharif season	1490.40	1437.60	—
	(iii) Rabi season	5675.00	5605.20	—
	(d) Fertilizer requirement (in metric ton):			
	(i) Nitrogen	44.50	37.20	—
	(ii) Phosphate	23.00	19.80	—
	(iii) Potash	19.00	13.00	—
3.	Cash expenditure (in Rs.)	64,41,015.80	—	94,00,113.90
4.	Production (in ’000 metric ton):			
	(a) Jute	306.00	302.85	—
	(b) Sugarcane	259.00	81.50	—
	(c) Rice	870.00	843.70	—
	(d) Wheat	136.26	112.50	—
	(e) Mustard	60.54	54.40	—
	(f) Potato	110.00	98.60	—
5.	Profit (in Rs.)	1,25,00,000.00	1,10,86,621.61	—

Table 3
Data description for utilization of productive resources, production rate, cash expenditure and market price

Production activity	MH	MD	WC	FR			PA	CE	MP
				N	P	K			
Jute	61.02	124	60	20	20	20	2538.00	8,577.98	980.00
Sugarcane	40.52	247	30	200	100	100	59,283.00	23,031.57	1500.00
Aus	61.02	84	25	40	20	20	2076.00	6,700.94	646.00
Aman	40.52	89	12	20	20	20	1885.00	6,811.57	540.00
Boro	38.51	111	48	100	50	50	3401.00	10,508.44	564.50
Wheat	36.36	74	12	100	50	50	2301.00	7,685.76	700.00
Mustard	36.36	47	6	80	40	40	795.00	5,093.10	1150.00
Potato	36.36	119	20	150	75	75	17,779.00	22,527.05	190.00

Note: MH = machine hour (hrs/ha), MD = mandays (days/ha), WC = water consumption (inch/ha), FR = fertilizer (kg/ha), PA = production achievement (kg/ha), CE = cash expenditure (Rs/ha), MP = market price (Rs./qtl).

(c) Water consumption goals:

(i) $\mu_6 : 0.295x_{11} + 0.147x_{21} + 0.123x_{31} - 12.405 + d_6^- - d_6^+ = 1$ (Prekharif).

(ii) $\mu_7 : 0.227x_{42} - 27.227 + d_7^- - d_7^+ = 1$ (Kharif).

(iii) $\mu_8 : 0.688x_{53} + 0.172x_{63} + 0.086x_{73} + 0.287x_{83} - 79.304 + d_8^- - d_8^+ = 1$ (Rabi).

(d) Fertilizer requirement goals:

(i) $\mu_9 : 0.003x_{11} + 0.021x_{21} + 0.005x_{31} + 0.003x_{42} + 0.014(x_{53} + x_{63}) + 0.110x_{73} + 0.021x_{83} - 5.096 + d_9^- - d_9^+ = 1$ (N).

(ii) $\mu_{10} : 0.006(x_{11} + x_{31} + x_{42}) + 0.031x_{21} + 0.016(x_{53} + x_{63}) + 0.013x_{73} + 0.023x_{83} - 6.188 + d_{10}^- - d_{10}^+ = 1$ (P).

(iii) $\mu_{11} : 0.003(x_{11} + x_{31} + x_{42}) + 0.017x_{21} + 0.008x_{53} + 0.007x_{63} + 0.013x_{73} + 0.017x_{83} - 1.667 + d_{11}^- - d_{11}^+ = 1$ (K).

3. *Cash expenditure goal* :

$$\mu_{12} : 3.177 - (0.290x_{11} + 0.008x_{21} + 0.002x_{31} + 0.002x_{42} + 0.004x_{53} + 0.003x_{63} + 0.002x_{73} + 0.008x_{83}) + d_{12}^- - d_{12}^+ = 1.$$

4. *Production achievement goals* :

(a) $\mu_{13} : 0.806x_{11} - 96.143 + d_{13}^- - d_{13}^+ = 1$ (Jute)
(b) $\mu_{14} : 0.334x_{21} - 0.459 + d_{14}^- - d_{14}^+ = 1$ (Sugarcane)
(c) $\mu_{15} : 0.079x_{31} + 0.072x_{42} + 0.129x_{53} - 32.080 + d_{15}^- - d_{15}^+ = 1$ (Rice)

(d) $\mu_{16} : 0.097x_{63} - 4.735 + d_{16}^- - d_{16}^+ = 1$ (Wheat)
(e) $\mu_{17} : 0.142x_{73} - 9.714 + d_{17}^- - d_{17}^+ = 1$ (Mustard)
(f) $\mu_{18} : 1.560x_{83} - 8.649 + d_{18}^- - d_{18}^+ = 1$ (Potato)

5. *Profit goal*:

$$\mu_{19} : 0.0176x_{11} + 0.063x_{21} + 0.011x_{31} + 0.014x_{42} + 0.020x_{53} + 0.011x_{63} + 0.007x_{73} + 0.024x_{83} - 7.844 + d_{19}^- - d_{19}^+ = 1.$$

Now, following the proposed procedure, the executable FGP model under a given priority structure can be obtained by (2.3). Here, in the solution process, four priority factors P_i $(i = 1, 2, 3, 4)$ are considered for achievement of the aspired levels of the stated fuzzy goals, and they are executed under four different priority structures using the *software LINGO (Ver 6.0)*.

The results obtained for different Runs are presented in Table 4.

In Table 4, the value of the weights involve with the deviational variables at different priority levels can easily be introduced by using (2.4) in the execution process.

The production achievement of the crops and their membership values for different land allocation plans under the Runs are displayed in Table 5.

Now following the procedure, the *Euclidean distances* for the membership values of the crop production goals achieved under the successive Runs are found as

$$D_1 = 1.004, \; D_2 = 0.126, \; D_3 = 1.414, \; D_4 = 1.417$$

The results reflect that the minimum distance (D_2) is 0.126. Thus, the priority structure under the Run-2 is an appropriate one for the optimal cropping plan in the decision making horizon.

The resulting annual profit is Rs. 1,28,59,977.20.

Note 1. It may be noted that the resulting membership values of all the fuzzy production goals are achieved to the highest degree (unity) or almost nearly all of it. Actually, it is to be observed here that the aspired levels of the crop production goals are fully satisfied or nearly achieved by utilizing the available productive resources including land within their specified tolerance ranges.

In this context, it may be pointed out that when a fuzzy goal is achieved between its aspiration level and the given tolerance limit, the membership value of it is found between 0 and 1. If the aspiration level is exactly achieved or has achieved more of it, the membership value becomes 1 (see [14]). Again, for achievement of a fuzzy goal to its specified tolerance limit or any value beyond of it, the membership value would be 0. This situation can also be followed from the characterization of membership functions for the fuzzy goals.

Now, the production structure for the existing cropping plan (recorded during the planning year 1999–2000) is presented in Table 6.

The achieved annual profit for the existing cropping plan is Rs. 1,20,29,138.00.

A comparison of the model solution with the result in Table 6 shows that a better cropping plan is achieved under the proposed approach in the decision-making environment.

Note 2. If the additive FGP approach proposed by Tiwari et al. [27], where the objective is to maximize the sum of membership functions (μ_{ij}) subject to $\mu_{ij} \leqslant 1$ in the decision making environment, is used to the example presented here, then the obtained solution is as given in Table 7.

Here, the achieved annual profit is Rs. 81,94,129.23.

The results indicate that the proposed approach is a superior one in the context of allocation of land in an agricultural system.

4. Conclusion

The FGP approach to cropping plan in an agricultural system demonstrated in the paper provides a new look into the way of analyzing the different farm-related activities in an imprecise decision-making environment. The main advantage of the proposed approach is that the decision for

Table 4
Land allocation plan under different priority structures

Run	Priority achievement function	x_{11}	x_{21}	x_{31}	x_{42}	x_{53}	x_{63}	x_{73}	x_{83}
1	$P_1\left(\sum_{k=1}^{3} w_{1k}^- d_k^-\right)$, $P_2\left(\sum_{k=13}^{18} w_{2k}^- d_k^-\right)$, $P_3\left(\sum_{k=6}^{8} w_{3k}^- d_k^- + w_{3,19}^- d_{19}^-\right)$, $P_4\left(\sum_{k=4}^{5} w_{4k}^- d_k^- + \sum_{k=9}^{12} w_{4k}^- d_k^-\right)$	120.567	4.369	5.034	124.20	183.897	59.218	18.464	6.187
2	$P_1\left(\sum_{k=1}^{3} w_{1k}^- d_k^-\right)$, $P_2\left(\sum_{k=13}^{18} w_{2k}^- d_k^-\right)$, $P_3(w_{3,19}^- d_{19}^-)$, $P_4\left(\sum_{k=4}^{12} w_{4k}^- d_k^-\right)$	120.567	4.369	98.426	124.20	126.890	59.218	75.472	6.187
3	$P_1(w_{1,19}^- d_{19}^-)$, $P_2\left(\sum_{k=1}^{3} w_{2k}^- d_k^-\right)$, $P_3\left(\sum_{k=13}^{18} w_{3k}^- d_k^-\right)$, $P_4\left(\sum_{k=4}^{12} w_{4k}^- d_k^-\right)$	16.614	4.369	63.997	124.20	147.905	59.218	54.456	6.187
4	$P_1\left(\sum_{k=13}^{18} w_{1k}^- d_k^-\right)$, $P_2\left(\sum_{k=1}^{3} w_{2k}^- d_k^-\right)$, $P_3\left(\sum_{k=6}^{8} w_{3k}^- d_k^- \; w_{3,19}^- d_{19}^-\right)$, $P_4\left(\sum_{k=4}^{5} w_{4k}^- d_k^- + \sum_{k=9}^{12} w_{4k}^- d_k^-\right)$	120.567	0	151.568	124.20	94.451	59.218	44.844	6.189

Table 5
Production achievement of the crops and their membership values

Run	(Production achievement, membership value)					
	Jute	Sugarcane	Rice	Wheat	Mustard	Potato
1	(305.999, 0.999)	(259.007, 1)	(870.001, 1)	(136.261, 1)	(14.679, 0)	(109.999, 0.999)
2	(305.999, 0.999)	(259.007, 1)	(870.002, 1)	(136.261, 1)	(60.00, 0.912)	(109.999, 0.999)
3	(42.166, 0)	(259.007, 1)	(869.999, 0.999)	(136.261, 1)	(43.293, 0)	(109.999, 0.999)
4	(305.999, 0.999)	(0, 0)	(870, 1)	(136.261, 1)	(35.651, 0)	(110.034, 1)

Table 6
Land allocation and production of crops recorded in the year 1999–2000

	Jute	Sugarcane	Rice	Wheat	Mustard	Potato
Land allocation ('000 ha)	128.8	1.20	314.9	52.2	66.5	3.7
Production achievement ('000 metric ton)	325.926	68.9	816.8	120.1	52.8	65.9

Table 7
Production achievement and their membership values under additive FGP model

Crop	Jute	Sugarcane	Rice	Wheat	Mustard	Potato
(Production, μ_{ij}) ('000 metric ton)	(113.644, 0)	(81.514, 0)	(545.013, 0)	(136.261, 1)	(60, 1)	(109.999, 0.999)

proper allocation of cultivable land for production of seasonal crops can be made on the basis of the need to society. Again, under the framework of the proposed model, other different environmental constraints (crisp/fuzzy) can easily be incorporated and a proper cropping plan can be made without involving any computational difficulty.

An extension of the proposed approach for fuzzily described different input parameters involved with different farm planning problems may be one of the current research problems. However, it is hoped that the method outlined in this paper may open up many new vistas in to the way of making decisions in complex agricultural planning situations in the current fuzzy multiobjective decision making arena.

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