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Multi-Objective Fuzzy Linear Programming for Land Allocation Under Different Crops in Bhagwanpur Distributary

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ABSTRACT

In India, attracting youths in agriculture and making it a sustainable and profitable venture is a big challenge. Optimization techniques play an important role in planning and decision making about agricultural activities. A study was undertaken in Bhagwanpur distributary of Vaishali Branch Canal in Gandak Canal Command Area, Bihar to optimally allocate land area under different crops (rice and maize in kharif, wheat, lentil,potato in rabi and green gram in summer) in such a manner that maximizes net return, maximizes crop production and minimizes labour requirement employing simplex linear programming method and Multi Objective Fuzzy Linear Programming (MOFLP) method. Maximum net return, maximum agricultural production, and minimum labour required under defined constraints (including 10% affinity level of farmers to rice and wheat crops) as obtained employing Simplex method were ₹ 3.7×10^8, 5.06×10^7 Kg and 66,092 man days, respectively, whereas Multi Objective Fuzzy Linear Programming (MOFLP) method yielded compromised solution with net return, crop production and labour required as ₹ 2.43×10^8, 3.42×10^7 Kg and 1,78,494 man days, respectively. As the affinity level of farmers to rice and wheat crops increased from 10% to 40%, maximum net return and maximum production as obtained from simplex linear programming method and MOFLP followed an decreasing trend and minimum labour required followed an increasing trend. MOFLP may be considered as one of the best capable methods of providing a compromised solution, which can fulfil all the objectives at a time.

KEYWORDS

Crop production, Labour requirement, MOFLP, Net return Optimization techniques

INTRODUCTION

Agriculture is being practiced in India, since time immemorial. It plays a crucial role in Indian economy and its importance can't be undermined. But, somehow due to many risks and uncertainties involved, it is not able to attract youth of India and is not being considered sustainable and reliable venture. In the initial era, though availability of natural resources, primarily land and water was same but due to less population, requirement was also less. Now, in order to feed ever increasing population of our country, it is required to think scientifically and systematically and act accordingly to consistently produce more from limited resources. The selection of crops to be sown in the fields by the farmers, mostly depend on their past experience, affinity to particular crops, discussion with neighboring farmers, links with extension agencies and exposure to new knowledge, availability of market, storage and transport facilities, investment capacity and expected returns. But they don't really know any scientific method, which can suggest them possible opportunities to understand the impact of inputs, outputs and factors affecting agricultural production and profit. Timely availability of quality input and its application at appropriate time gives optimum output, but such standard condition may not be available to farmers due to many prevailing constraints. Due to this, farmers fail to have optimum crop production. But, if farmers plan in advance about farming activities after properly assessing the available resources and management strategies under prevailing constraints, their crop production and returns may increase many folds. Optimization techniques can help farmers in planning and decision making about agriculture.

Linear programming (LP) is one of the tools to mathematically determine the land allocated under different crops to maximize net return. Upadhyaya (2017) evolved an optimum land allocation plan to improve farm productivity at ICAR-RCER, Patna employing simplex method of linear programming and observed that existing practice was least profitable. Upadhyaya (2018) employed modified simplex method of linear programming in the command of Bhagwanpur distributary of Vaishali Branch canal under Gandak irrigation scheme in Bihar with a single objective of maximizing net return and developed optimum land allocation plan under different crops. Single objective linear programming problem can be solved easily by simplex method and to solve multi-objective problems, Multi Objective Fuzzy Linear Programming (MOFLP) technique may be employed. Fuzzy mathematical programming has been investigated and developed in several research studies. One of the important early contributions in fuzzy linear programming was given by Zimmermann (1976) and in detail by Zimmermann (2001). In fuzzy multi-objective programming, one of the main approaches in dealing with fuzzy models is the possibility theory. The basic work in possibility theory was introduced by Dubois and Prade (1988). Their work has presented the foundation of the possibility programming approach, which has been applied to fuzzy linear single objective and multi objective programming. Chanas (1989) proposed a fuzzy programming in MOLP problem and it was solved by parametric approach. Czyzak (1989) applied a fuzzy linear programming method for solving multi-criteria agricultural planning problems under uncertainty. Lai and Hawng (1992) considered MOLP problem with all parameters, having a triangular possibility distribution. They used an auxiliary model and it was solved by MOLP methods. Sakawa *et al.* (1994) presented an interactive fuzzy satisfying method for large-scale FMOLP problems with the block angular structure. Saad (1995) suggested a procedure for solving FMOLP problems and some basic stability

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notions have been characterized for FMOLP problems. Chang *et al.* (1997) explained the advantage of Fuzzy Multi Objective Optimization over deterministic approach as 1) fuzzy uncertainties embedded in the model parameters can be directly reflected and communicated into the optimization process 2) the variation or vagueness of the decision maker's aspiration level in the model can be incorporated and there by generate a more confident solution set for decision maker 3) regardless of the orientation of decision maker's aspiration level (maximization or minimization), each objective or goal has its own independent membership function and different aspiration levels. The study considered above aspects in the multi objective Fuzzy Linear Programming (FLP) frame work by incorporating three objectives net benefits, crop production and labour employment for selection of the compromise irrigation plan. Slowinski (1998) has studied uncertainty and vagueness effect in agricultural production. Sakawa *et al.* (2001) have presented an interactive fuzzy approach for multi-objective linear programming problems. *Stanciulescu et al.* (2003) have proposed a new methodology that considers fuzzy decision variables for solving FMOLP problems. The FMOLP problem has been transformed to its crisp equivalent, using possibility programming. Sahoo *et al.* (2006) developed Fuzzy Multi Objective and Linear Programming based management models in order to optimally plan and manage land, water and crop system in Mahanadi Kathajodi delta in eastern India. The Models are used to optimize the economic return, production and labour utilization, and to search the related cropping pattern and intensities with specified land, water, fertilizer and labour availability, and water use pattern constraints. These non-structural models facilitated the conjunctive use of available surface water and groundwater resources. A comparative evaluation along with the benefit-cost ratio of the existing and proposed farming system was also presented. The crisp MOLP problems, has been solved using the global criterion method and the distance functions method is proposed by Iskander (2008). In agricultural development planning, Peidro *et al* (2009) proposed fuzzy optimization for supply chain planning under supply, demand and process uncertainties. Zeng *et al.* (2010) also applied Fuzzy Multi Objective Linear Programming Model (FMLOP) to crop area planning of Liang Zhouregion, Gansu province of northwest China, and then obtained the optimal cropping patterns under different water saving levels and satisfaction grades for water resources availability of decision makers. Veeramani *et al.* (2011) studied Fuzzy Multi Objective Linear Programming Problem in which both technological coefficient and resources were considered fuzzy with linear membership function and discussed method through an example. Behera and Rana (2013) applied MOFLP technique to study various integrated farming system scenarios and reported that MOFLP technique is advantageous as compared to single objective planning problem because it provides compromised solution satisfying all the objectives.

Keeping this in view the study conducted in Bhagwanpur distributary of Vaishali Branch Canal in Gandak Canal Command Area, Bihar as reported by Upadhyaya (2018) was revisited with the following objectives:-

I. To optimally allocate land area under different crops in such a manner that maximizes net return, maximizes crop production and minimizes labour requirement employing simplex linear programming method.
II. To develop a compromised solution employing Multi Objective Fuzzy Linear Programming (MOFLP) method

MATERIALS AND METHODS

STUDY AREA

This study was carried out in Bhagwanpur distributary of Vaishali branch Canal in Gandak Command Area. From Gandak river, Tirhut Main Canal (TMC) emanates and Vaishali Branch Canal (VBC) takes off from Tirhut Main Canal at 553.89 RD. Vaishali Branch Canal area is bounded by Baya River and Bhushali Distributary. Vaishali, Samastipur, Muzaffarpur and Gopalganj districts come under VBC. VBC runs up to 48 kms from the head gate and then it is known as Bhagwanpur Distributary which is 33 kms in length. The study focuses over the Bhagwanpur distributary, which lies in Saraiya block of Muzaffarpur district and takes off from 155 RD of VBC of Gandak Irrigation Scheme as shown in Fig. 1 (Source: Gandak Command Area Development Authority, Muzaffarpur). The command area lies in the tail end of Gandak Irrigation scheme. The command area served by Bhagwanpur distributary constitutes of Saraiya block of Muzaffarpur district and Vaishali block of Vaishali district. It is ridge line canal and runs through 9 and 16 villages of Muzaffarpur and Vaishali districts, respectively and lies in latitude between $25^0 52'30''$ and $26^0 3'0''$N and longitude between $85^0 7'30''$ and $85^0 15'0''$ E. State Agriculture Department reports indicated that the total cultivable command area is 1,841 ha and the gross command area is 2,250 ha. Major crop was rice in 70% area followed by maize crop in rest of the area during kharif season; wheat as the major crop in 60% area, followed by lentil in 20% area and potato in 20% area during rabi season; and green gram in limited area (5%) during summer season. About 89% of total rainfall (945 mm) occurs during mid June to end of September and very little during summer and winter season. In summer season, temperature varies between 35^0 and 42^0C, whereas in winter season temperature remains between 15^0C and 30^0C.

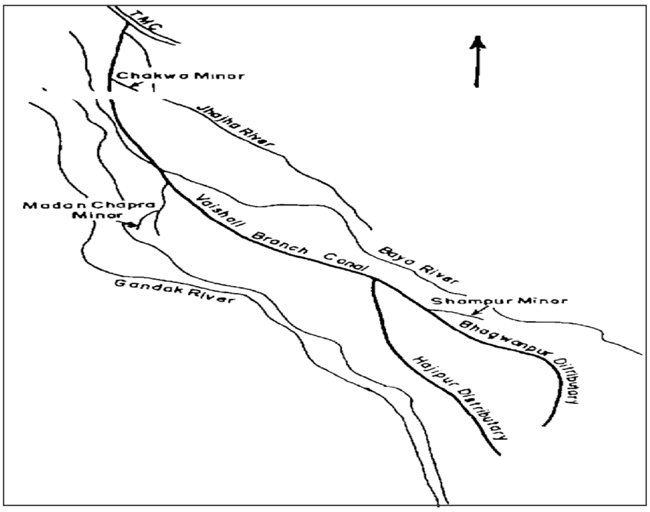

Fig 1: Vaishali Branch Canal Command Area of Bihar

FIELD SURVEY

One hundred farmers were randomly selected to represent whole command of Bhagwanpur distributary and data about inputs applied (like seeds, fertilizer, insecticides/pesticides, land preparation, farm implements, water and labour) outputs produced (like main product and by-product) along with cost were collected through developed questionnaire. Meteorological data for 30 years were collected from Muzzafarpur and Vaishali district from IMD, Patna. Data about canal water and ground water availability and supply was also collected. Discharge of some representative tube wells was measured by filling a tank of 500 litre capacity and dividing it with time required to fill the tank. A total of 971 tube wells of shallow to medium depth mostly diesel operated were found in the project area. The average discharge of tube well and average annual operation hours were estimated as 54 m^3h^{-1} and 87 h, respectively. The total ground water resources availability was estimated to be 456.17ha-m. The canal water availability during different months was also collected from Divisional office of Water Resources Department, Sarraiya and the total canal water availability was estimated to be 466.74ha-m. Same data of crop water requirement, irrigation requirement and labour requirement, cost of input, income from output and net return as mentioned by Upadhyaya and Roy (2018) was used and is mentioned again in Table 1 and 2 for ready reference.

Table 1: Average yield, crop water requirement, irrigation requirement and labour requirement of various crops

Sl. No.	Crop	Average yield (Kg)	Crop water Crequirement (mm)	Net irrigation requirement (mm)	Labour requirement (Man days ha^{-1})
1.	Rice	4500	1182	698	164
2.	Maize	4000	336	132	84
3.	Wheat	3500	267	222	75
4.	Lentil	2000	240	193	62
5.	Potato	25000	193	135	88
6.	Green gram	1500	253	211	40

Table 2: Cost of input, income from output ant return of different crops

Sl. No.	Crop	Cost of input	Income	Net return
1.	Rice	45120	70500	25380
2.	Maize	25960	60250	34290
3.	Wheat	38430	60500	22070
4.	Lentil	33695	73000	39305
5.	Potato	87000	250000	163000
6.	Green gram	24870	72750	47880

It was also realized during field survey that farmers have special affinity to rice crop during kharif season and wheat crop during rabi season. So, in this study affinity level for rice and wheat crop varying between 10% and 40% was considered. Similarly another affinity of farmers was to sow lentil and green gram in more than 30% of net sown area and farmers don't want to sow green gram in more than 50% of net sown area in summer season. Based on the collected data and interactions with farmers of the project area, the problem consisting of three objective functions and inequality constraints was formulated and is given below.

Objective function 1: Maximization of Net Return (Z_{NR})

Max: $Z_{NR} = 25380\,A_R + 34290\,A_{Ma} + 22070\,A_W + 39305\,A_L + 163000\,A_P + 47880\,A_{Gg}$ (1)

Objective function 2: Maximization of farm Production (Z_P)

Max: $Z_P = 4500\,A_R + 4000\,A_{Ma} + 3500\,A_W + 2000\,A_L + 25000\,A_P + 1500\,A_{Gg}$ (2)

Objective function 3: Minimization of Labour requirement (Z_{LR})

Min: $Z_{LR} = 164\,A_R + 84\,A_{Ma} + 75\,A_W + 62\,A_L + 88\,A_P + 40\,A_{Gg}$ (3)

Constraints related to area

Constraint 1: $A_R \geq$ 10 to 40 % of total cultivable command area i.e 1841 ha (4)

Constraint 2: $A_L + A_{Gg} \geq 552.3$ (30% of total cultivable command area 1841 ha) (5)

Constraint 3: $A_R + A_{Ma} \leq 1841$ (6)

Constraint 4: $A_W + A_L + A_P \leq 1841$ (7)

Constraint 5: $A_{Gg} \leq 920.5$ (50% of total cultivable command area 1841 ha) (8)

Constraint 6: $A_W \geq$ 10 to 40 % of total cultivable command area i.e 1841 ha (9)

Constraint related to canal and ground water availability for use by crops

Constraint 7: $0.498\,A_R + 0.132\,A_{Ma} \leq 466.74$ (canal water availability ha-m) (10)

Constraint 8: $0.2\,A_R + 0.222\,A_W + 0.193\,A_L + 0.135\,A_P + 0.211\,A_{Gg} \leq 456.17$ (ground water availability ha-m) (11)

Here A_R, A_{Ma}, A_W, A_L, A_P, and A_{Gg} are area in (ha) to be allocated under rice, maize, wheat, lentil, potato and green gram, respectively.

Three objective functions of maximization of net return (Rs), maximization of farm production (Kg) and minimization of labour required (Man-days) were considered in this study. Problem was solved first by employing simplex method of linear programming considering all the three objective functions one by one with all the reported constraints. The solutions provided area allocated under different crops and corresponding maximum and minimum objective function values. The lower and upper limits of each objectives are also obtained.

Fuzzy Linear Programming Approach

Considering objective functions as fuzzy and membership functions linear, the problem can be redefined as:

Find X such that

$C\,X \leq Z$ (12)

$A\,X \leq B$ (13)

and $X \geq 0$ (14)

The membership function of fuzzy set decision model μ_D may be written as

$\mu_D(X) = \min_z \{\mu_Z(X);\ z = 1, 2, 3\}$ (15)

$\mu_Z(X)$ is the degree to which X fulfils the fuzzy inequality $CX \leq Z$. The membership functions $\mu_Z(X)$ for different objective functions are given below.

For maximization of net return

$\mu_Z(X) = 0$ for $Z_{NR} \le Z_L$

$$\mu_Z(X) = \left[\frac{Z_{NR} - Z_L}{Z_U - Z_L}\right] \text{ for } Z_L \le Z_{NR} \le Z_U$$

$\mu_Z(X) = 1$ for $Z_{NR} \ge Z_U$

For maximization of farm production

$\mu_Z(X) = 0$ for $Z_P \le Z_L$

$$\mu_Z(X) = \left[\frac{Z_P - Z_L}{Z_U - Z_L}\right] \text{ for } Z_L \le Z_P \le Z_U$$

$\mu_Z(X) = 1$ for $Z_P \ge Z_U$

For minimization of labour requirement

$\mu_Z(X) = 1$ for $Z \le Z_{LR}$

$$\mu_Z(X) = \left[\frac{Z_U - Z_{LR}}{Z_U - Z_L}\right] \text{ for } Z_L \le Z_{LR} \le Z_U$$

$\mu_Z(X) = 0$ for $Z_{LR} \ge Z_U$ (16)

Here Z_U and Z_L are highest and lowest acceptable levels of the objective functions that can be obtained with individual optimization. $\mu_Z(X)$ reflects the degree of achievement and its value varies between 0 (no achievement) and 1 (perfect achievement). When a new variable λ representing degree of satisfaction is introduced, Multi Objective Fuzzy Linear Programming problem is formulated as (equation 17 to 21):

$$\text{Max } \lambda \quad (17)$$

Subject to

$$\left[\frac{Z_{NR} - Z_L}{Z_U - Z_L}\right] \ge \lambda \quad (18)$$

$$\left[\frac{Z_P - Z_L}{Z_U - Z_L}\right] \ge \lambda \quad (19)$$

$$\left[\frac{Z_U - Z_{LR}}{Z_U - Z_L}\right] \ge \lambda \quad (20)$$

$$0 \le \lambda \le 1 \quad (21)$$

RESULTS AND DISCUSSION

The results obtained for individual maximization and minimization of objective functions and constraints mentioned above are presented in Table 3, 4, and 5, respectively.

Table 3: Maximum and minimum net return and corresponding area allocated under different crops at different affinity levels

	Affinity level 10%		Affinity level 20%	
Net return (₹)	Maximum (Z_U)	Minimum (Z_L)	Maximum (Z_U)	Minimum (Z_L)
	370750114	30443697	318137617	39179242
A_R	184.1	184.1	368.2	368.2
A_{Ma}	1656.9	0	1472.8	0
A_W	184.1	184.1	368.2	368.2
A_L	0	552.3	95.3	552.3
A_P	1656.9	0	1377.5	0
A_{Gg}	733.6	0	457.1	0
	Affinity level 30%		Affinity level 40%	
Net return (₹)	Maximum (Z_U)	Minimum (Z_L)	Maximum (Z_U)	Minimum (Z_L)
	231302437	47914787	129494365	56650332
A_R	552.3	552.3	736.4	736.4
A_{Ma}	1288.7	0	757.7	0
A_W	552.3	552.3	736.4	736.4
A_L	440.6	552.3	552.3	552.3
A_P	848.1	0	287.5	0
A_{Gg}	111.7	0	0	0

Table 4: Maximum and minimum farm production and corresponding area allocated under different crops at different affinity levels

	Affinity level 10%		Affinity level 20%	
Farm Production (kg)	Maximum (Z_U)	Minimum (Z_L)	Maximum (Z_U)	Minimum (Z_L)
	50623300	2301250	44150550	3774050
A_R	184.1	184.1	368.2	368.2
A_{Ma}	1656.9	0	1472.8	0
A_W	184.1	184.1	368.2	368.2
A_L	0	0	95.3	0
A_P	1656.9	0	1377.5	0
A_{Gg}	733.6	552.3	457.1	552.3
	Affinity level 30%		Affinity level 40%	
Farm Production (kg)	Maximum (Z_U)	Minimum (Z_L)	Maximum (Z_U)	Minimum (Z_L)
	31824450	5246850	17214100	6719650
A_R	552.3	552.3	736.4	736.4
A_{Ma}	1288.7	0	757.7	0
A_W	552.3	552.3	736.4	736.4
A_L	440.6	0	552.3	0
A_P	848.1	0	287.5	0
A_{Gg}	111.7	552.3	0	552.3

Table 5: Maximum and minimum Labour requirement and corresponding area allocated under different crops at different affinity levels

	Affinity level 10%		Affinity level 20%	
Labour requirement (Man days)	Maximum (Z_U)	Minimum (Z_L)	Maximum (Z_U)	Minimum (Z_L)
	366383	66092	357128	110092
A_R	375 .4	184.1	368.2	368.2
A_{Ma}	1465.6	0	1472.8	0
A_W	184.1	184.1	368.2	368.2
A_L	0	0	95.3	0
A_P	1656.9	0	1377.5	0
A_{Gg}	552.3	552.3	457.1	552.3
	Affinity level 30%		Affinity level 40%	
Labour requirement (Man days)	Maximum (Z_U)	Minimum (Z_L)	Maximum (Z_U)	Minimum (Z_L)
	346669	154092	299189	198092
A_R	552.3	552.3	736.4	736.4
A_{Ma}	1288.7	0	757.7	0
A_W	552.3	552.3	736.4	736.4
A_L	440.6	0	552.3	0
A_P	848.1	0	287.5	0
A_{Gg}	111.7	552.3	0	552.3

It may be observed from Table 3 that at 10% affinity level maximum net return is ₹ 3.7×10^8 and lower limit of net return is ₹ 3.0×10^7, whereas at 40% affinity level maximum net return is ₹ 1.29×10^8 and lower limit of net return is ₹ 5.66×10^7. It indicates that maximum net return is declining with increase in affinity level to rice and wheat crops because rice and wheat crops are less remunerative crops compared to other crops and are being allocated in more area with increase in affinity level from 10% to 40%. Minimum net return is increasing because area allocated under rice and wheat crops is increasing with increase in affinity level.

Upper and lower limits of farm production and area allocated under different crops corresponding to different affinity levels are reported in Table 4. At 10% affinity level maximum farm production is 5.06×10^7 Kg and lower limit of farm production is 2.30×10^6 Kg, whereas at 40% affinity level maximum farm production is 1.72×10^7 Kg and lower limit of farm production is 6.72×10^6 Kg. It also follows exactly the same trend as net return.

The maximum and minimum labour required and area allocated under different crops corresponding to different affinity levels are reported in Table 5. At 10% affinity level, upper limit of labour required is 3,66,383 man days and lower limit is 66,092 man days, whereas at 40% affinity level upper limit of labour required is 2,99,189 man days and lower limit is 1,98,092. Results indicate that upper limit of labour requirement decreases with increase in affinity level because area allocated under rice and wheat crops has increased from 375.4 ha and 184.1 ha to 736.4 ha under both the crops and area allocated under maize, lentil, potato and green gram has changed from 1465.6 ha to 757.7 ha, 0 to 552.3 ha, 1656.9 to 287.5 ha and 552.3 to 0 ha, respectively. The lower limit of labour requirement has increased with increase in affinity level for rice and wheat crops. This happened because more area was allocated under rice and wheat crops requiring more labour.

Since all the three solutions obtained above are based on optimization of three single objective functions, it is not possible to suggest a single solution. Fuzzy multi objective linear programming formulation is capable of providing compromised solution. Results are presented in Table 6.

It may be observed from Table 6 that Net return at 10% and 40% affinity level varied between ₹ 2.43×10^8 and ₹ 1.03×10^8; farm production between 3.42×10^7 Kg and 1.34×10^7 Kg; and labour requirement between 1,78,494 man days and 2,34,483 man days. It may be noted that all the values of net return, farm production and labour required corresponding to different affinity levels as obtained after employing Multi Objective Fuzzy Linear Programming (MOFLP) lie between lower and upper limits determined by single objective linear programming approach. Results indicate that net return and farm production decrease with increase in affinity level but labour requirement increase with increase in affinity level. The decreasing trend in case of net return and farm production and increasing trend in labour requirement with increase in affinity level is well justified because by increasing affinity level more area under less remunerative rice and wheat crops is being allocated. Degree of satisfaction (λ) is varying between 0.626 and 0.669, which is quite satisfactory.

Table 6: Solution by Multi Objective Fuzzy Linear Programming

Fuzzy solution	Affinity level 10%	Affinity level 20%	Affinity level 30%	Affinity level 40%
Net return (₹)	243379569	214282814	170646459	103272762
Farm Production (Kg)	34233750	29904050	23344350	13436400
Labour requirement (Man days)	178494	202069	217795	234483
A_R	184.1	368.2	552.3	736.4
A_{Ma}	0	0	0	113.0
A_W	184.1	368.2	552.3	736.4
A_L	0	0	0	239.5
A_P	1277.3	1045.2	723.9	245.8
A_{Gg}	552.3	552.3	552.3	312.8
λ	0.626	0.628	0.669	0.640

CONCLUSIONS

In order to maximize net return and production and minimize labour requirement, simplex method of linear programming has been employed and area allocated under different crops have been determined. But when there are more than one objective function and that too conflicting in nature, linear programming approach shows incapability in providing an appropriate solution. Multi Objective Fuzzy Linear Programming (MOFLP) approach proves to be advantageous over single objective linear programming approach, because it provides a compromised solution, which satisfies all the objectives.

Net return and farm production at affinity level between 10% and 40% as obtained by MOFLP show a decreasing trend and vary between ₹ 2.43×10^8 and ₹ 1.03×10^8; and 3.42×10^7 Kg and 1.34×10^7 Kg and labour requirement show an increasing trend between 1,78,494 man days and 2,34,483 man days, respectively. All these values lie between lower and upper limits of net return, farm production and labour requirement as obtained by single objective function problem formulations, so it may be concluded that Multi Objective Fuzzy Linear Programming (MOFLP) approach provides a compromised and more reliable solution and seems to be a better approach in studying such type of problems.

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