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Developing Optimal Cropping Plan for Small and Marginal Farms in Central Uttar Pradesh

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ABSTRACT

Agricultural developmental planning is essential for better utilization of available resources to fulfil the present demand and to protect natural resources for future utilization. Sugarcane is grown as a cash crop by majority of small and marginal farmers in Central U.P. The optimal crop plan for sugarcane-based farming system has been developed by using the Sen's improved weighted sum multi-objective programming (WSMOP).There are number of methods for solving MOO problems such as goalprogramming, weighted sum method and new averagingmethods. The finding reveals that the Sen's Improved WSMOP method gives superior results for MOO problems as compare to other methods, when the high preference is given to an objective or few objectives or presence of dominance amongst objectives. This technique has generated efficient compromised solution in achieving all the four objectives simultaneously. The findings conclude that Sen's Improved WSMOP technique have better solutions for agricultural crop planning at micro and macro level.

KEYWORDS: *Multi-Objective Optimization, Sen's Multi-Objective Optimization, Normalization, Optimal Average Techniques, Weighted Sum Multi-Objective Programming*

I. Introduction

Sugarcane production and its diversified products processing has pivotal role in socio-economic transformation through Agri-based rural industrialization.It is cultivated on nearly 5 million hectares which covers about 2.9 percent of gross cropped area and produces almost 400 million tons with average productivity 80 tons per hectare in India. Globally, India ranks second in sugarcane and sugar production next to Brazil. About 7 -7.5 million sugarcane farmers and number of agricultural laborer's are engaged in its cultivation, ancillary services and diversified processing. Besides it, nearly 0.5-0.6 million skilled and semi-skilled workers are also engaged in sugar industry which is the second largest Agri-processing industry after textile. It has active role in socio-economic development through inter sectoral dynamism and rural resources mobilization. In UttarPradesh sugar mills procures sugarcane from farmers through cooperative societies. There were 3.5 million farmers, out of which nearly 83 percent have small and marginal land holding size less than 1.0 ha supplied sugarcaneto 119operational sugar mills during sugar crushing season 2019-20.

Linear programming techniques are used for the efficient allocation of scares production resources to optimize the objective function with a given set of constraints or resource availability. These techniques have been used to optimize (maximize/ minimize) single objective functionsubject to given set of constraints. In agricultural developmental planning, decision makers ultimate goals are to optimize resource use and maximize profits. It is difficult to optimize multiple conflicting objectives at a time. It was realized to explore the possibilities of generating the compromising solution that achieves all the objectives simultaneously. Several methods have been developed for solving multi-objective optimization problems. Sen [1] developed a new method of solving the Multi-Objective Programming (MOP) problems to optimize multiple conflicting objectives with common set of constraints simultaneously. A combined objective function is formulated with normalization of all the objectives by their optimal values. Sen's MOP has been successfully applied for resource use planning in agriculture [2], [3],[4],[5], [6], [7]. Several new methods of MOP have been proposed during past three decades [8], [9] [10]. Sen evaluated these methods and suggested improved methods [11], [12], [13] for solving MOP problems. These methods are efficient in generating a compromised solution with equal preference to all the objectives under consideration. When the objectives are givenunequal preferences, the modified MOP methods are required. An improved weighted sum method of MOP [14] suggested by Sen has been applied for developing optimal cropping plan for small and marginal farmers of central Uttar Pradesh.

II. MATHEMATICAL STRUCTURE OF MULTI-OBJECTIVE OPTIMIZATION MODEL

2.1 Sen's Multi-Objective Optimization Model

Sen's multi objective optimization model is detailed as below:

Optimize Z= Max. Z_1, ...Max. Z_m, Min. Z_{m+1}.........Min. Z_n

$$Max.Z = \sum_{i=1}^{m} \frac{Zi}{|\theta i|} - \sum_{j=m+1}^{n} \frac{Zj}{|\theta j|}$$

Subject to;

AX ≥ , ≤ , = b

X ≥ 0

Where;

Z is the combined objective function, Z_i is the i^{th} maximization objective function and Z_j is the j^{th} minimization objective function. $C_i$is coefficient of i^{th}crop,│Θi│ is the optimal value of i^{th} maximization objective function and │Θj│ is the optimal value of j^{th} minimization objective function. X are the crops and A is the resource use coefficients matrix.

2.2 Crops grown by the small and marginal farmers

Crops grown by small and marginal farmers in sugarcane-based farming system in central U.P. are given in Table 1.

Table 1: Crops grown by the small and marginal farmers

Code	Crop	Code	Crop
X_1	Paddy	X_9	Green Pea/ Vegetable Pea
X_2	Maize	X_{10}	Lahi/ Mustard
X_3	Kharif pulses	X_{11}	Banana
X_4	Til or Sesamum	X_{12}	Sugarcane with inter crops
X_5	Potato	X_{13}	Rabi Vegetables
X_6	Sugarcane	X_{14}	Oat/ Barley
X_7	Wheat	X_{15}	Fodder Berseem
X_8	Rabi pulses (Gram/ Lentil)	X_{16}	Tomato

2.3 Objective Functions

There were four objective functions formulated for maximizing farmers income and employment with minimum use of irrigation and Fertilizer. The objective functions are mentioned in the table 2.

Table 2: Objective functions

Objective Function	X_i							
	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8
Max. Z_1 (Income in Rs.)	26840	24650	16774	14594	28641	73255	31662	22985
Max. Z_2 (Employment in Days)	102	86	42	26	126	148	68	41
Min. Z_3 (Water Use in mm)	1800	650	350	350	700	1500	450	275
Min. Z_4 (Fertilizer in Kg.)	260	220	85	60	320	425	310	80

table 2 contd.

Objective Function Contd.	X_i							
	X_9	X_{10}	X_{11}	X_{12}	X_{13}	X_{14}	X_{15}	X_{16}
Max. Z_1 (Income in Rs.)	27885	25330	95500	94658	42775	24450	30570	62278
Max. Z_2 (Employment in Days)	106	35	154	167	94	37	41	69
Min. Z_3 (Water Use in mm)	320	250	1600	1350	650	320	750	300
Min. Z_4 (Fertilizer in Kg.)	125	120	430	410	205	190	140	145

2.4 Constraints

Constraints were as detailed below:

Kharif Land:

$X_1+X_2+X_3+X_4+X_6+X_{11}+X_{12} \leq 0.69$

Rabi Land:

$X_5+X_7+X_8+X_9+X_{10}+X_{11}+X_1+X_{13}+X_{14}+X_{15}+X_{16} \leq 6.9$

Kharif Cash:

$48044X_1+36613X_2+38823X_3+19784X_4+86897X_6+62488X_{11}+102458X_{12} \leq 105000$

Rabi Cash:

$64234X_5+44087X_7+34144X_8+63853X_9+32576X_{10}+62488X_{11}+102458X_{12}+62345X_{13}+38824X_{14}+31274X_{15}+68427X_{16} \leq 105000$

Farm Yard Manure: $101X_1+63X_2+110X_5+85X_6+110X_{11}+105X_{12}+50X_{13} \leq 145$

Minimum area: $X_1 \geq 0.14$, $X_2 \geq 0.06$, $X_3 \geq 0.06$, $X_4 \geq 0.06$, $X_5 \geq 0.04$, $X_6 \geq 0.18$, $X_7 \geq 0.08$, $X_8 \geq 0.02$, $X_9 \geq 0.02$, $X_{10} \geq 0.03$, $X_{11} \geq 0.03$, $X_{12} \geq 0.15$, $X_{13} \geq 0.04$, $X_{14} \geq 0.02$, $X_{15} \geq 0.03$, $X_{16} \geq 0.04$

2.5 Solution of Single and Multi-Objective Optimization

All the four objective functions namely income and employment maximization; irrigation water and fertilizer use minimization have been achieved with single and multi-objective optimization techniques. The achievements of all theobjectives have been given in table 3. The maximization of income has increased the income by 19.05 percent but employment by 2.94 percent only with more use of water and fertilizer. Similar results in optimization of remaining objectives have been obtained. The solution obtained using Sen's MOP was also not appropriate. The income of the small and marginal sugarcane farmers has increased by 9.71 percent only, employment level has decreased by 10.89 percent which is not desirable. The decrease in the use of irrigation water and fertilizer applied by small and marginal farmers have been significant levels of 26.81 and 19.85 respectively. The sugarcane farmers foremost preference is the maximization of their income with lesser preference to employment, irrigation water saving and fertilizer use. Therefore, Sen's Weighted Sum Multi Objective Programming technique has been used to obtain most desirable cropping plan for sugarcane-based farming system in Central Uttar Pradesh.

Table 3: Single and Multi-Objective Optimization for Small and Marginal Farms cropping plan

Item	Existing	Individual Optimization				Sen's MOP
		Max. Z_1	Max. Z_2	Min, Z_3	Min. Z_4	
Z_1	48417.80	57643.00 (19.05)	45618.30 (-6.66)	39195.00 (-19.05)	37643.00 (-22.26)	53122.60 (9.71)
Z_2	102.83	105.85 (2.94)	134.77 (31.06)	78.31 (-23.85)	75.16 (-26.91)	91.64 (-10.89)
Z_3	1006.65	1077.95 (7.08)	896.15 (-10.98)	718.82 (-28.60)	727.70 (-27.72)	736.82 (-26.81)
Z_4	276.55	290.08 (4.89)	298.77 (8.03)	213.03 (-22.97)	188.57 (-31.82)	221.67 (-19.85)

2.6 Sen's Weighted Sum Multi Objective Programming

$$Max.Z = \sum_{i=1}^{m} wi \frac{Zi}{|\theta i|} - \sum_{j=m+1}^{n} wj \frac{Zj}{|\theta j|}$$

Subject to;

AX ≥ / ≤/ = b

X ≥ 0

$|\theta i|$ is the optimal value of i^{th} maximization objective function and $|\theta j|$ is the optimal value of j^{th} minimization objective function. arithmetic mean ofthe coefficients the of j^{th} minimization objective function. $w_{i\&}w_j$ are the weights assigned to i^{th} and j^{th} objective function and $\sum_{i=1}^{m} w_i = 1$, A is the coefficient matrix to decision variables X and b is the constraint vector.

III. SOLUTION OF WEIGHTED SUM MULTI OBJECTIVE PROGRAMMING

The existing and improved Weighted Sum Multi-Objective Programming Methods (WSMOP) has been used to develop optimal cropping plans for small and marginal farmers. These farmers grow sugarcane as main cash crop in the central U.P. There could be number options for assigning weights to the four conflicting objective functions. A limited number of weight possibilities may be used for solving the given objective function with given set of constraints matric set. The relative weights w1, w2, w3, and w4 could be fixed as (0.9,01,0,0), (0.8,0.1,0.1,0), (0.7,0.1,0.1,0.1),(0.6,0.2,0.1,0.1),(0.5,0.2,0.2,0.1),(0.4,0.2,0.2,0.2),(0.25,0.25,0.25,0.25), (0.3,0.25, 0.25,0.2)etc. This MOO problem was solved by assigning weights (0.7,0.1, 0.1,0.1) as in actual farm conditions sugarcane farmers given more weight to maximize income as compare to employment and to minimize irrigation water use and fertilizer application. The results obtained are given in Table 4.

The solution of improved WSMOP is presented in Table 4. The income of the small and marginal sugarcane farmers can be increased by 15.73 percent and employment by4.59 percent only. The application of irrigation water and fertilizer has decreasedby 4.94 and 0.19 percent respectively. The findings of the study reveals that the Sen'sImproved Weighted Sum Multi Objective Programming (WSMOP) technique has given better optimization solution for improved cropping planfor sugarcane-based farming system in Central Uttar Pradesh.

Table 4: Optimization using Weighted Sum Multi Objective Programming for Small and Marginal Farms.

Item	Existing	WSMOP
Z_1 Income (Rs)	48417.80	56034.20 (15.73)
Z_2 Employment in Days	102.83	107.56 (4.59)
Z_3Irrigation Water in mm	1006.65	956.95 (-4.94)
Z_4 Fertilizer used in Kg.	276.55	276.03 (-0.19)

The optimal cropping plan developed through WSMOP technique for small and marginal farmsof central U.P. presented in table 5. It indicates that the area under sugarcane, paddy and wheat should be reduced, if farmers follow the optimal plan. The acreage allocated to sugarcane with intercrops and fodder crop berseem has to increase to accomplish the conflicting objectives of income and employment maximization and irrigation water and fertilizer use minimization to save precious natural resources, improve farmers income and sustain crop productivity in long term.

Table 5. Existing and Optimal Cropping Plan on Small and Marginal Farms

Existing Cropping Pattern				Optimal Cropping Pattern	
Crop	Code	Area (ha.)	Percent area	Area (ha.)	Percent area
Paddy	X_1	0.14	14.00	0.07	8.33
Maize	X_2	0.06	6.00	0.03	3.57
Kharif Pulses	X_3	0.06	6.00	0.03	3.57
Til	X_4	0.06	6.00	0.03	3.57
Potato	X_5	0.04	4.00	0.02	2.38
Sugarcane	X_6	0.18	18.00	0.09	10.7
Wheat	X_7	0.08	8.00	0.04	4.76
Rabi Pulses	X_8	0.02	2.00	0.02	2.38
Green Pea (Veg.)	X_9	0.02	2.00	0.01	1.19
Lahi/ Mustard	X_{10}	0.03	3.00	0.015	1.78
Banana	X_{11}	0.03	3.00	0.015	1.78
Sugarcane with Intercrop	X_{12}	0.15	15.00	0.41	48.81
Rabi Veg.	X_{13}	0.04	4.00	0.07	8.33
Oat/Barley	X_{14}	0.02	2.00	0.005	0.59
Berseem (Fodder)	X_{15}	0.03	3.00	0.15	17.85
Tomato	X_{16}	0.04	4.00	0.02	2.38
Gross Cropped Area (ha.)		1.00	100.00	0.84	100.00

IV. CONCLUSION

The results obtained in this study reveals that the Sen's Improved WSMOP method gives superior results in solving the multi objective optimization problems as compare to the existing MOP techniques. When farmers high priority is to a particular objective (income maximization in the present study), the application of WSMOP is required. The improved WSMOP techniques has generated an efficient compromised solution in achieving all the four objectives simultaneously. The research results concluded that the Sen's Improved WSMOP technique have generated anacceptable solution for suitable crop planning.

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