



*The World's Largest Open Access Agricultural & Applied Economics Digital Library*

**This document is discoverable and free to researchers across the globe due to the work of AgEcon Search.**

**Help ensure our sustainability.**

Give to AgEcon Search

AgEcon Search

<http://ageconsearch.umn.edu>

[aesearch@umn.edu](mailto:aesearch@umn.edu)

*Papers downloaded from **AgEcon Search** may be used for non-commercial purposes and personal study only. No other use, including posting to another Internet site, is permitted without permission from the copyright owner (not AgEcon Search), or as allowed under the provisions of Fair Use, U.S. Copyright Act, Title 17 U.S.C.*

*No endorsement of AgEcon Search or its fundraising activities by the author(s) of the following work or their employer(s) is intended or implied.*

## Optimising Cropping Pattern in Eastern Uttar Pradesh Using Sen's Multi Objective Programming Approach<sup>§</sup>

Maina Kumari<sup>a\*</sup>, O.P. Singh<sup>a</sup> and Dinesh Chand Meena<sup>b</sup>

<sup>a</sup>Department of Agricultural Economics, Institute of Agricultural Sciences,  
Banaras Hindu University, Varanasi-221005, Uttar Pradesh

<sup>b</sup>Indian Institute of Soil and Water Conservation, Research Centre, Agra-282006, Uttar Pradesh

### Abstract

The study has attempted evolving suitable cropping patterns for increasing farm income with less use of irrigation water in eastern Uttar Pradesh. The conflict noticed in achieving of both the objectives individually has been addressed by using Sen's Multi Objective Programming (MOP) model. The optimized cropping pattern has shown an increase of 7 per cent in farm income and a reduction of 6 per cent in use of irrigation water. The study has suggested some policy implications for improving agricultural production per drop of water.

**Key words:** Multi objective programming (MOP), consumptive water use, optimal cropping pattern, blue water, green water, area allocation, linear programming, Uttar Pradesh

**JEL Classification:** Q15

### Introduction

To meet the increasing demand for food of ever increasing population it is necessary to either to bring additional area under cultivation and/or increase production per unit area. The productivity being 2-3 times higher in irrigated agriculture than in rainfed agriculture, it is imperative to bring more area under irrigation. But due to increasing demand for water from industrial and domestic sectors, it is rather difficult to bring additional area under irrigation. Rather the share of water for agriculture is reducing due to priority allocations to domestic and industrial sectors. The other option is the optimal allocation of resources including

land and water to achieve maximum returns through increasing production per unit area and per drop of water (Gadge *et al.*, 2014). Linear programming is a method of determining a profit maximizing combination of farm enterprises that is feasible with respect to a set of fixed farm constraints. The application of linear programming for whole farm planning could aid farmers to efficiently adapt to a changing economic and technological environment as well as to enhance food security (Otoo *et al.*, 2015). In the agriculture sector, extensive studies have been done on the application of linear programming technique for allocation of limited resources (Igwe *et al.*, 2011; Majeke, 2013; Bamiro *et al.*, 2015), but mostly to achieve a single objective at a time. For achieving two or more objectives, the application of Multi Objective Programming (MOP) is required.

The study has attempted to develop an optimal crop plan for enhancing farm income with less irrigation water. The presence of conflict in these objectives has

\* Author for correspondence

Email: maina.meena1309@gmail.com

§ This paper is drawn out of the PhD thesis entitled, A study of crop-water productivity in different regions of Uttar Pradesh, India, of the first author submitted to the Department of Agricultural Economics, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, in 2016

necessitated the application of Sen's MOP model (1983) for achieving these. The optimal cropping plan has been developed for the eastern Uttar Pradesh. The results obtained for achieving single as well as multiple objectives have been compared with the existing water-use, income, and cropping pattern.

## Data and Methodology

Uttar Pradesh is the largest state of India in population (220.7 million) and fourth largest in area (24.1 Mha). Agriculture forms an integral part of state's economy and the state is popularly known as the granary or bread-basket of India. Given its large size, diverse geography, climate and topography, the state has been divided into 4 regions, namely western, central, eastern and Bundelkhand. The eastern Uttar Pradesh having 29 districts covers about 35 per cent of total geographical of the state. The average normal annual rainfall in this region is 1025 to 1214 mm and 1025 mm and the climatic conditions are moist sub-humid to dry sub-humid. The main soil types found in the region are sandy loam, loam, calcareous, clayey deep alluvial, light alluvial calcareous clay, sandy loam red yellow clay. Despite good average annual rainfall, about 40 per cent area of the cultivated land is rainfed and 60 per cent is irrigated, of which 42 per cent is partly irrigated. The farming is dominated by small and marginal farmers— 82 per cent farmers have landholding of less than 1 ha (average holding size being 0.39 ha per farmer) and the remaining farmers have land size between 1 and 2 ha.

The lack of irrigation water at the proper time constrains crop production in the region. The major portion of cultivated area is captured by rice-wheat cropping system. There is ample scope of introducing less water-intensive and short-duration crops for sustaining crop productivity and attaining agriculture growth in the region.

The study is based on the secondary data on cropped area, production and yield of major crops. These were collected from various publications of the Ministry of Agriculture and Farmer Welfare, Government of India, and Government of Uttar Pradesh for the year 2013-14. The data on minimum support prices (MSP) have been collected from the publication of Commission for Agriculture Costs and Prices for

2013-14. The value of each crop was estimated by multiplying its yield with its MSP.

## Analytical Tools

### Estimation of Crop Water Requirement

It is important to know the water requirement of a crop (from sowing to harvest) as different crops have different water requirements depending upon climate, type of soil, method of cultivation, effective rainfall, etc. The CropWat model developed by the Food and Agriculture Organization (FAO) has been used for estimation of crop water requirement. The crop water requirement (in  $\text{m}^3/\text{ha}$ ) is calculated from the accumulated crop evapo-transpiration ( $ET_c$ ) measured in mm/day over the complete crop growing period. Many past researchers have used CropWat model to estimate the crop water requirement (Bouraima *et al.*, 2015; Amarasinghe *et al.*, 2010; Laghari *et al.*, 2014; Allen *et al.*, 1998). The evapo-transpiration ( $ET_c$ ) was calculated by using formula (1):

$$ET_c = K_c * ET_0 \quad \dots(1)$$

where,  $ET_0$  is the reference crop evapo-transpiration and  $K_c$  is the crop coefficients.

The concept of reference crop evapo-transpiration was introduced by the FAO to analyze the evaporative demand of the atmosphere independently of crop type, crop development and crop management practices. The climate parameters affect the  $ET_0$ . The reference crop evapo-transpiration has been calculated on the basis of FAO Penman-Monteith Equation (2) (Smith *et al.*, 1992; Allen *et al.*, 1994; 1998):

$$ET_0 = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{273} U_2 (e_a - e_d)}{\Delta + \gamma (1 + 0.34U_2)} \quad \dots(2)$$

where,  $ET_0$  is the reference crop evapo-transpiration ( $\text{mm}/\text{day}$ );  $R_n$  is the net radiation at the crop surface ( $\text{MJ}/\text{m}^2/\text{day}$ );  $G$  is the soil heat flux ( $\text{MJ}/\text{m}^2/\text{day}$ );  $T$  is the average air temperature ( $^{\circ}\text{C}$ );  $U_2$  is the wind speed measured at 2 m height ( $\text{M}/\text{S}$ );  $e_a$  is the saturation vapour pressure curve ( $\text{kPa}$ );  $e_d$  is the actual vapour pressure ( $\text{kPa}$ );  $e_a - e_d$  is the vapour pressure deficit ( $\text{kPa}$ );  $\Delta$  is the slope of the vapour pressure curve ( $\text{kPa}/^{\circ}\text{C}$ ) and  $\Gamma$  is the psychrometric constant ( $\text{kPa}/^{\circ}\text{C}$ ). The crop coefficient accounts for the actual crop canopy and aerodynamic resistance relative to the hypothetical

reference crop. The crop coefficients serve as an aggregation of the physical and physiological differences between a certain crop and the reference crop.

### Estimation of Blue and Green Water Use

The CropWat model is also used to estimate blue (artificial irrigation/diverted water) and green water (rain water) for crop production. The CropWat model provides total water requirement for a given crop for the whole crop cycle. The model also apportions total crop water requirement into blue and green waters. The model provides irrigation scheduling for fortnightly as well as for whole crop cycle.

The concept of green and blue water was introduced by Falkenmark (1995). He describes green water as the rainwater that infiltrates into the root zone of plants and used for biomass production. The water that either runs off from the soil surface or percolates beyond the root zone to form groundwater, by contrast, is called the blue water. Several experts have attempted to provide definitions to these two waters since the terms were introduced. In this process, Xu (2013) defines the green water as water that comes from precipitation and is stored in soil and then consumed by vegetation. Fader *et al.* (2011) define the blue water as water taken from rivers, reservoirs, lakes and aquifers and used for irrigation.

### Optimization Models

Several studies have reported non-optimal use of inputs in crop production in India. Most studies on optimization of resources are concerned only with maximization of farm income and employment. In this study, optimization of resources has been considered in a wider prospective taking scarcity of water for agriculture as well as other uses. Therefore, optimal cropping plans have been formulated for maximization of income and minimization of water-use individually as well as simultaneously due to conflict in these objectives. The optimization models may be described as: (i) Maximization of Income, (ii) Minimization of Water Use and (iii) Multi-Objective Programming Model.

#### Maximization of Income

$$\text{Maximize } Z = \sum_{j=0}^n I_j X_j \quad (j = 1, 2, 3, \dots, n)$$

$$\text{subject to } \sum_{j=1}^n (a_{ij} X_j) \geq b_i \quad (i = 1, 2, 3, \dots, n)$$

such that,

$$X_1 \geq 0; X_2 \geq 0; \dots; X_n \geq 0$$

where,  $Z$  is the total income of all farmers in the region;  $X_j$  is the level of  $j^{\text{th}}$  activity on all farms in the region;  $I_j$  is the income per unit of  $j^{\text{th}}$  activity;  $a_{ij}$  is the amount of  $i^{\text{th}}$  resources used per unit of the  $j^{\text{th}}$  activity and  $b_i$  is the available quantity of  $i^{\text{th}}$  resource.

#### Minimization of Water Use

$$\text{Minimize } Z = \sum_{j=0}^n W_j X_j \quad (j = 1, 2, 3, \dots, n)$$

$$\text{subject to, } \sum_{j=1}^n (a_{ij} X_j) \geq b_i \quad (i = 1, 2, 3, \dots, n)$$

such that,

$$X_1 \geq 0; X_2 \geq 0; \dots; X_n \geq 0$$

where,  $Z$  is the total water use by all farms in the region;  $X_j$  is the level of  $j^{\text{th}}$  activity on all farms in the region;  $W_j$  is the water use per unit of  $j^{\text{th}}$  activity;  $a_{ij}$  is the amount of  $i^{\text{th}}$  resources used per unit of the  $j^{\text{th}}$  activity and  $b_i$  is the available quantity of  $i^{\text{th}}$  resource.

The results of the individual optimization of the objectives show the presence of conflict between them. Under such a situation, we use Sen's multi-objective optimization approach. There are several multi-objective optimization models as given by White (1990), Stoecker (1985), Sinha and Sinha (2004), Anderle *et al.* (1994), McNamara (1971), Annetts and Audsley (2002), Abdelaziz (2007), Sen (1983) and Rozakis *et al.* (2001), etc. The multi-objective optimization model used in the study is described below:

#### Multi Objective Programming Model

In this study, Sen's Multi Objective Programming (MOP) model has been used for achieving all the objectives simultaneously. The MOP model may be explained as:

$$\text{Maximize } Z = \frac{\sum_{j=1}^n I_j X_j}{W_1} - \frac{\sum_{j=1}^n W_j X_j}{W_2}$$

$$\text{subject to } \sum_{j=1}^n (a_{ij} X_j) \geq b_i \quad (i = 1, 2, 3, \dots, n)$$

such that,

$X_1 \geq 0; X_2 \geq 0; \dots; X_n \geq 0$

$W_1$  and  $W_2 > 0$

$W_1$  and  $W_2$  are individual optima

All the 21 major crops grown in the eastern Uttar Pradesh have been considered in the optimization plan. The water requirement for each crop is estimated as described above. The net incomes over total costs for all the crops have been estimated on the basis of information available from Commission for Agricultural Costs and Prices. The cropping pattern in the year 2013-14 has been taken as base for formulating alternative cropping pattern for enhancing income with lesser water-use in the region. For generating a realistic optimal cropping pattern, the fluctuations (maximum & minimum) in the area under each crop during the past 10 years have been put as constraints in all the models.

## Results and Discussion

### Consumptive Water Demand for Different Crops in Eastern Uttar Pradesh

The results obtained from CropWat model are presented in Table 1 and the consumptive water-use does not include water losses during water supply from source to crop field that includes evaporation, percolation, seepage, etc. from the conveyance channel. Most of the crops grown during the *kharif* season use more green water supplemented by blue water, whereas crops grown in the *rabi* and *zaid* seasons meet their water requirement from irrigation water and somewhat fulfilled by off-season rainfall. The total water requirement (blue and green water) is recorded highest for sugarcane (16113 m<sup>3</sup>/ha), and followed by rice (*zaid*) (10791 m<sup>3</sup>/ha). Similarly, wheat and rice (*kharif*) crops are also more water demanding with the quantum of 8136 m<sup>3</sup>/ha and 8985 m<sup>3</sup>/ha. On the other hand, water requirement has been recorded minimum by the *rabi* pulses, tobacco and barley using 2256 m<sup>3</sup>/ha, 2329 m<sup>3</sup>/ha and 2380 m<sup>3</sup>/ha of water, respectively.

### Cropping Pattern, Income and Water Use in Existing and Alternative Plans in Eastern Uttar Pradesh

The results of maximization of income, minimization of water-use and multi objective

**Table 1. Crop wise consumptive water demand in eastern Uttar Pradesh**

Crop	Eastern Uttar Pradesh		
	Blue water	Green water	Total water requirement (million cubic meters)
Rice ( <i>kharif</i> )	3389	5595	8985
Maize ( <i>kharif</i> )	1420	2907	4328
Jowar	722	2949	3672
Bajra	722	2949	3672
Small millets	755	3025	3781
Arhar	540	3269	3809
Urd ( <i>kharif</i> )	540	3269	3809
Moong ( <i>kharif</i> )	540	3269	3809
Til	1430	3196	4626
Groundnut	1430	3196	4626
Soybean	1517	3079	4596
Wheat	6959	1176	8136
Barley	1847	532	2380
Gram	1754	502	2256
Pea	1754	502	2256
Masoor	1754	502	2256
Rapeseed- mustard	5036	1814	6850
Linseed	5036	1814	6850
Sunflower	5036	1814	6850
Potato	2297	636	2933
Tobacco	1897	532	2429
Sugarcane	11278	4835	16113

programming for optimization of water resources and maximization of income are presented in Table 2. We develop three alternative optimization plans: (a) maximization of farmers' income; (b) minimization of water use for crop production; and (c) multi objective optimization. The single objective function, viz. maximization of income has resulted in an increase of income by 9.51 per cent over the existing income of ₹ 300180 million, whereas water-use has reduced by 2.38 per cent from the existing water-use of 70074 million cubic meters (MCM). In the case of minimization of water-use, there is a decrease in water-use by 11.73 per cent compared to the existing use of water i.e. 70074 MCM. But income from crop production has also reduced by the 37.03 per cent from the current level of ₹ 300180. This indicates the presence of conflict in the achievement of both the objectives at a time.



**Table 2. Income and water use in the existing and alternative plans in eastern Uttar Pradesh**

Particulars	Existing Plan	Individual optimization		Multiple objective programming
		Max. income	Min. water	
Income (million ₹)	300180	328737 (9.51)	189018 (-37.03)	322266 (7.36)
Water use (MCM)	70074	68404 (-2.38)	61851 (-11.73)	65727 (-6.20)

*Note:* Figures within the parentheses shows the percentage increase/decrease over the existing level

However, the solution generated with multi objective programming (MOP) seems more realistic.

Multi objective programming provides optimal solutions to the contradicting results from optimization of individual objectives. In the case of income, there is 7.36 per cent increase which is less than the individual objective of income optimization of income, even it is found better than the existing income level. On the contrary, water-use decreased by 6.20 per cent from

the existing level of water use. Therefore, it could be concluded that multi objective optimization is a better solution over individual optimization, but a compromised solution over the individual optimizations.

The results of the existing cropping pattern along with optimized cropping pattern for eastern Uttar Pradesh achieved by using MOP are presented in Table 3. The gross cropped area increased in the optimized plan to 8722 thousand ha from 8553 thousand ha in

**Table 3. Existing and optimal cropping patterns in eastern Uttar Pradesh**

Crops	Existing area (000 ha)	Per cent gross cropped area	Optimized area (000 ha)	Per cent gross cropped area	Per cent change in area share
Rice ( <i>kharif</i> )	3183	37.21	2908	33.34	-3.87
Maize ( <i>kharif</i> )	216	2.52	390	4.47	1.95
Jowar	56	0.66	118	1.35	0.69
Bajra	112	1.31	143	1.64	0.33
Small millets	7	0.08	7	0.08	0.00
Arhar	164	1.92	262	3.00	1.08
Urd ( <i>kharif</i> )	41	0.48	44	0.50	0.03
Moong ( <i>kharif</i> )	2	0.02	2	0.02	0.00
Til	22	0.25	16	0.18	-0.07
Groundnut	13	0.15	17	0.20	0.04
Sugarcane	435	5.09	307	3.52	-1.57
Wheat	3673	42.95	3402	39.01	-3.94
Barley	48	0.56	149	1.71	1.15
Gram	124	1.45	360	4.13	2.68
Masoor	143	1.67	245	2.80	1.14
Pea	79	0.92	144	1.66	0.74
Rapeseed - mustard	106	1.24	70	0.80	-0.44
Linseed	12	0.14	11	0.13	-0.01
Sunflower	0.34	0.00	0.17	0.00	-0.17
Potato	114	1.33	124	1.42	0.09
Tobacco	3	0.03	4	0.04	0.01
Gross cropped area	8553	100	8722	100	

the existing pattern. Though, different crops are cultivated on different area shares, still there is scope for reallocation of natural resources to different crops, so that income generation could be improved from the alternative plan along with minimization of water-use.

The eastern Uttar Pradesh is one of the major food grains producing region of the state. In the existing cropping pattern, cereals account for 85.21 per cent and pulses 4.62 per cent in gross cropped area (GCA). Among cereals, rice and wheat are the principal crops and their relative share in GCA is 37.21 per cent and 42.95 per cent, respectively. Among pulses, arhar, masoor and gram are the major crops constituting 1.92 per cent, 1.67 per cent and 1.45 per cent of GCA, respectively. In regard to oilseed crops, rapeseed-mustard is the leading crop with 1.24 per cent share in GCA followed by groundnut, til and linseed with very small shares in GCA. Sugarcane and potato are also important cash crops in the region and share 5.09 per cent and 1.33 per cent of gross cropped area, respectively.

After optimization, the share of area in GCA under rice, sugarcane and wheat has reduced by 3.87 per cent, 1.57 per cent and 3.94 per cent, respectively. Beside these crops, rapeseed-mustard and til crops also show a reduction in area share under cultivation by 0.44 per cent and 0.07 per cent, respectively. On the other hand, increase in share of area is the highest for gram (2.68%). As compared to the existing cropping pattern, the share of maize, barley, masoor, arhar, pea, jowar, bajra, potato and groundnut also increases by 1.95 per cent, 1.15 per cent, 1.14 per cent, 1.08 per cent, 0.74 per cent, 0.69 per cent, 0.33 per cent, 0.09 per cent and 0.04 per cent, correspondingly. Pulse crops have seen a significant rise in their area share in GCA from 4.62 per cent in the existing cropping pattern to 12.11 per cent in the optimized cropping pattern. The share of area of water-intensive crops (rice, wheat and sugarcane) decreases by 9.38 per cent in the optimized cropping pattern. The rice is largely replaced by jowar, bajra and maize, while wheat is substituted by gram and barley. The area under different crops is reallocated in optimized cropping pattern for maximizing income generation and minimizing use of water for irrigation.

## Conclusions and Policy Implication

The study has attempted to develop an optimal cropping pattern for enhancing farm income and reducing less water for irrigation using Sen's Multi Objective Programming (MOP) model. The results have been compared under the existing plan and optimized plan for income, water-use and change in area under different crops. The study has made following recommendations:

- The farmers should be guided to follow the indicative optimal cropping pattern, which can maximize net returns with water saving;
- Cultivation of water-intensive crops (rice, wheat and sugarcane) should be restricted up to a certain level which neither affect the water resources badly nor exert the pressure on stocks and supply of the crop produce;
- The Government should encourage crop diversification (by including less water demanding crops in cropping pattern) in the region for efficient and sustainable use of groundwater resources and improving agricultural production and growth.

## Acknowledgement

The authors thank the anonymous referee for helpful suggestions.

## References

- Abdelaziz, F.B. (2007) Multiple objective programming and goal programming: New trends and applications. *European Journal of Operational Research*, **177**: 1520-1522.
- Allen, R.G., Smith, M., Perrier, A. and Pereira, L.S. (1994) An update for the definition of reference evapotranspiration, *ICID Bulletin*, **43**(2): 1-34.
- Allen, R.G., Pereira, L.S., Raes, D. and Smith, M. (1998) *Crop Evapotranspiration-Guidelines for Computing Crop Water Requirements*. FAO Irrigation and Drainage Paper No. 56. Food and Agriculture Organization, Rome, Italy.
- Amarasinghe, U.A., Smakhtin, V., Sharma, B.R. and Eriyagama, N. (2010) *Bailout with White Revolution or Sink Deeper? Groundwater Depletion and Impacts in the Moga District of Punjab, India*. IWMI Research Report 138. International Water Management Institute, South Asia, India.

- Anderle, C., Fedrizzi, M., Giove, S. and Fuller, R. (1994) Fuzzy multiple objective programming techniques in modeling forest planning, In: *Proceedings of EUFIT'94 Conference*. September 20-23. Aachen, Germany, Verlag der Augustinus Buchhandlung, Aachen, pp. 1500-1503.
- Annetts, J.E. and Audsley, E. (2002) Multiple objective linear programming for environmental farm planning. *The Journal of the Operational Research Society*, **53**(9): 933- 943.
- Bamiro, O.M. Adediji, I.O., Otunnaiya, A.O., Soluade, W. and Ogunjobi, J.O. (2015) Enterprise combination in livestock sector in Southwestern, Nigeria. *Journal of World Economic Research*, **4** (2): 38-44.
- Bouraima, K.A., Zhang, W. and Wei, C. (2015) Irrigation water requirements of rice using CropWat model in Northern Benin. *International Journal of Agricultural & Biological Engineering*, **8**(2): 58-64.
- Fader, M., Gerten, D., Thammer, N., Heinke, J., Lotze-Campen, H., Lucht, W. and Cramer, W. (2011) Internal and external green-blue agricultural water footprints of nations, and related water and land savings through trade. *Hydrology and Earth System Sciences*, **15**: 1641–1660.
- Falkenmark, M. (1995) *Coping with Water Scarcity under Rapid Population Growth*. In: Conference of SADC Ministers, Pretoria, South Africa. pp. 23–24.
- Gadge, S.B., Gorantiwar, S.D., kumar V. and Kothari, M. (2014) Linear programming approach for allocation of land and water resources in canal command area under surface method of irrigation- A case study. *International Journal of Innovative Research in Science, Engineering and Technology*, **3**(4): 153-160.
- Igwe, K.C., Onyenweaku, C.E. and Nwaru, J.C. (2011) Application of linear programming to semi-commercial arable and fishery enterprises in Abia State, Nigeria. *International Journal of Economics and Management Sciences*, **1**(1):75-81.
- Laghari, T.S., Khaliq, A., Shah, S.H.H., Ali, S., Shahzad, H. and Nasir, U. (2014) Analysis of rainfall data to estimate rain contribution towards crop water requirement using CropWat model. *Russian Journal of Agricultural and Socio Economic Sciences*, **12**(36): 9-17.
- Majeke, F. (2013) Optimum combination of crop farm enterprises: A case study of a small-scale farm in Marondera, Zimbabwe. *International Researcher*, **2**(1): 60-65.
- McNamara, J.F. (1971) Mathematical programming models in educational planning, *Review of Educational Research*, **41**(5): 419-446.
- Otoo, J., Ofori, K. and Amoah, F. (2015) Optimal selection of crops: A case study of small scale farms in Fanteakwa district, Ghana. *International Journal of Scientific & Technology Research*, **4**(5): 142-146.
- Rozakis, S., Souriea, J.C. and Vanderpooten, D. (2001) Integrated micro-economic modelling and multi-criteria methodology to support public decision-making: The case of liquid bio-fuels in France. *Biomass and Bioenergy*, **20**: 385-398.
- Sen, C. (1983) A new approach for multi-objective rural development planning, *The Indian Economic Journal*, **30**(4): 91-96.
- Sinha, S.B. and Sinha S. (2004) A linear programming approach for linear multi-level programming problems. *The Journal of the Operational Research Society*, **55**(3): 312-316.
- Smith, M., Allen, R.G., Monteith, J.L., Perrier, A., Pereira, L. and Segeren, A. (1992) *Report of the Expert Consultation on Procedures for Revision of FAO Guidelines for Prediction of Crop Water Requirements*. UN- Food and Agriculture Organization FAO, Rome, Italy 54p.
- Stoecker, A.L., Seidmann A. and Lloyd G.S. (1985) A linear dynamic programming approaches to irrigation system management with depleting groundwater. *Management Science*, **31**(4): 422-434.
- White, D.J. (1990) A bibliography on the applications of mathematical programming multiple objective methods. *The Journal of the Operational Research Society*, **41**(8): 669-691.
- Xu, J. (2013) Effects of climate and land-use change on green-water variations in the middle yellow river, China. *Hydrological Science Journal*, **58**(1): 106-117.

---

Received: November, 2016; Accepted: June, 2017



