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Planning of agricultural inputs in Ur watershed to maximize net benefit under limited resources

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ABSTRACT

Two models (CROPWAT and LINGO) were used to optimize the resource allocation and achieving higher efficiency in agricultural productivity. Quantitative evaluation of hydro-meteorology parameters was carried out for crop water and irrigation requirement planning using CROPWAT model. Whereas, LINGO model applied to determine the optimum land and water resources allocation to major crops of *kharif* and *rabi* season in the Ur watershed using agriculture data such as net income per ha which was calculated based on various sub factures, viz. cost of fertilizers and pesticides, cost of seeds, yield of crops, daily wages of labour and machine charges, selling base price of commodities. Results revealed that the crop water requirement in *kharif* season was 593 cm and in *rabi* season 421 cm, whereas irrigation requirement was 71.16 cm and 294.7 cm respectively. Because, the crop grown during *kharif* season require less irrigation water. Therefore only supplemental irrigation requirement have to be planned for *kharif* crops. But in *rabi* season, more irrigation water is required to bring whole area under cultivation. That's why the scenarios were considered based on available resources of watershed to fulfill the demand. Output of the CROPWAT model was used as input of the LINGO model for formulation of the linear programming equations under different scenario. There were three scenarios considered in each cropping seasons, viz. in *kharif* season (i) Existing scenario; (ii) Some need based crop scenario; (iii) Limitation with cash crop scenario; and in *rabi* season (i) Existing scenario with conventional method of wheat growing; (ii) Scenario under System of Wheat Intensification; (iii) Scenario under increasing 10% irrigation water. It was observed that the combination of both the models is appropriate for finding the optimal land and water resources allocation to the major crops in *kharif* and *rabi* season for maximizing net income of the watershed.

Key words: CROPWAT model, Crop water planning, Irrigation requirement, LINGO model, Optimization and linear programming

In arid, semiarid and rainfed region, generally agriculture faces regular, continuous and widespread drought which leads to sever water scarcity. The soils with its low productivity along with impending climate effects further aggravate the situations like food security. Semiarid and rainfed region follow the distress and crisis which simply cannot be explained by the absence or irregularity of rainfall (Sony and Goyal 2003). Neglecting traditional water management system and rampant unsustainable exploitation of natural resources pushes towards cultivation of water intensive cropping systems. At the same time using the traditional water management practices which lack scientific water management, directly affect agricultural productivity (Molden *et al.* 2007). For this, planning of the agricultural inputs is more important from both social and economic points of view (Doorenbos and Kassam 1979). With increasing population, there is always a need of more production to meet the ever increasing demand by either bringing new area under cultivation or increasing the productivity of existing land (Tavakkoli *et al*. 2010). But rapid urbanization and industrialization reduces the availability of land and water for agriculture activity (Kejne *et al.* 2003). As a result, grim situation happens in the agriculture sector, which needs of proper utilization of resources. Planning of agricultural input is the very crucial factor with limited available resources for maximizing net return (Sarker *et al.* 2002).

Optimal crop pattern and production of food crops with maximum profit is important information for agricultural planning using optimization methods (Singh *et al.* 2001). Data required to formulate optimization technique are land, water, crop production, production cost and net income (Rani 2012). There are many optimization techniques are available but the linear programming model is more popular owing to the proportionate characteristic of the agricultural allocation problems. Many problems can be formulated as linear programming problems (Dantzig 1963), and the linear programming has been used for optimizing agricultural inputs on farm level to maximize the net

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benefit (Heady 1954, Zhang *et al.* 1990, Campbell *et al.* 1992, Keith 1985, Tanko *et al.* 2006, Ion and Turek 2012, Wankhade and Lunge 2012). The development of linear programming is ranked among the most important scientific technique to plan the agricultural input and its assessment is generally accepted. Day by day, it is becoming the standard tool saving thousands or millions of rupees in agricultural sector (Sofi *et al.* 2015).

The present study concentrated on socio economic aspect of the primary stakeholders of the Ur river watershed in Tikamgarh district of Madhya Pradesh to maximize the net return through optimal allocation of agricultural inputs by using the linear programming model.

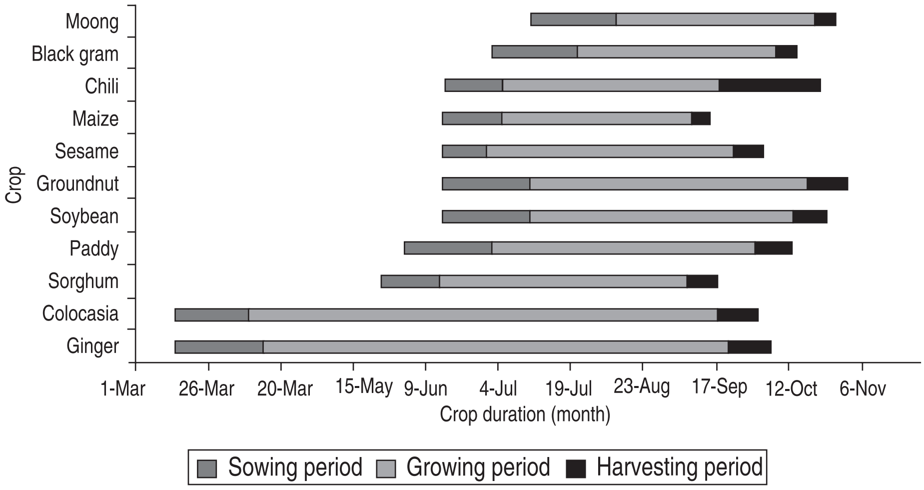

Fig 1 Crop Calendar of *kharif* season in Ur watershed.

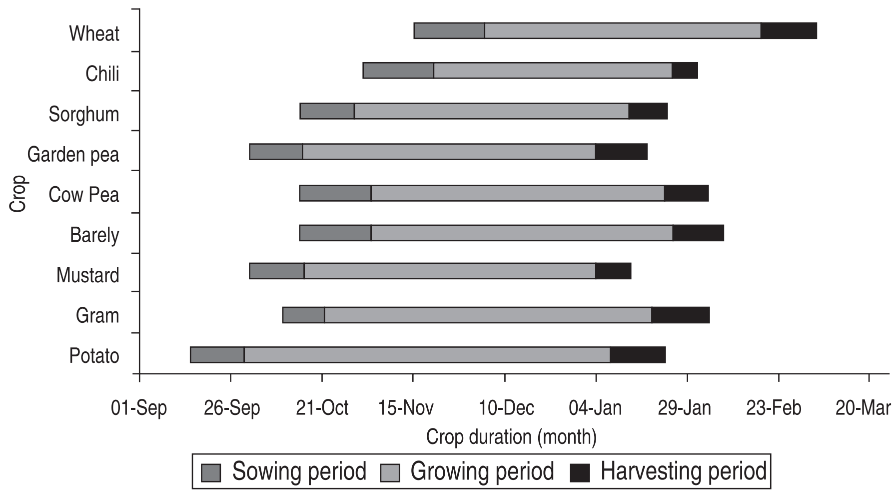

Fig 2 Crop Calendar of *rabi* season in Ur watershed.

MATERIALS AND METHODS

The present study was conducted in the Ur river watershed of Bundelkhand region in Tilkamgarh district of Madhya Pradesh. The study area represents the typical topography and geology of Bundelkhand region. The Ur river watershed lies on the Bundelkhand Plateau between the Jamni, a tributary of Betwa and Dhasan rivers. It extends between latitudes 24°35′0″ N to 25°05′0″ N and longitudes 78°50′0″ E to 79°10′0″ E. The total geographical area of the watershed is 990.37 sq km. The climate of the study area is semi arid with four seasons. The winter season extends from December to February followed by the summer season from March to mid June; rainy season from mid June to September and the transition season spans from October to November.

It was observed that most part of the study area is under agricultural land (58062 ha) which is about 58.64 % of the total watershed area. The scrub land is the second most dominant land use in the study area covering an area of 13118 ha. The area covered by settlement is 49.50 ha, whereas dense forest occupies an area of 110.50 ha. The river and water bodies cover the area of 85.48 ha. Forests are located towards the western portion of the watershed, whereas the snrubs are mostly located towards the south-western parts of the watershed.

Study area falls under four blocks of Tikamgah district. The distribution of the area under various blocks of Tikamgarh district falling in Ur river watershed is given in Table 1. The Jatara block covers of an area of 32494 ha which is about 33 % of total watershed area followed by Tikamgarh block covers 31597 ha (31.90 %); Baldevgarh covers 27265 ha (27.52 %) and Palera covers 7681 ha (7.75 %).

Crop calendar is a tool to provide timely information regarding planting, sowing and harvesting periods of adapted crops in the watershed throughout the year. For overall development of a watershed, it is very much important to have knowledge of seed rates, planting dates and other basic information related to crop production. Keeping in view these points season wise (*kharif* and *rabi*) crop calendar of

Table 1 Distribution of the area under various blocks in the Tikamgarh District

Block name	Area of block falling in watershed (ha)	Area of watershed (%)
Tikamgarh	31597	31.90
Palera	7681	7.75
Baldevgarh	27265	27.52
Jatara	32494	32.80

Ur watershed was developed which is shown in Fig 1 and 2.

The development of irrigation schedules and evaluation of irrigation practices are based on a daily soil-water balance using various options for water supply and irrigation management conditions. Procedure for calculation of crop water requirements and irrigation requirements are based on methodologies presented by Doorenbos and Pruit (1977). CROPWAT model was used for estimating reference crop evapotranspiration which is based on the Penman-Montieth approach. The crop data required for estimation of crop water requirement includes planting height, length of growing stages, and crop coefficient for different growing stages.

The crop factor was determined for each decade. Evapotranspiration of crop was determined by

$$ET_{crop} = K_c \times ET_0$$

Irrigation requirement was determined from ET_{crop} and effective rainfall by:

$$\text{Irrigation requirement} = ET_{crop} - \text{Effective rainfall}$$

Based on present information, existing scenario was used as base data for the model and other scenarios were generated for maximize the overall net benefit of the watershed.

The optimum allocation of available land and water resources was made to maximiz the net return by various crops.

Parameters of the model were grouped into two types: i. Decision variables: there were following decision variables considered for optimizing the income a. Crop types, b. Water requirement, and c. Net income per ha. ii. Constraints: a. Water, and b. Land.

A linear programming problem with "n" decision variables and "m" constraints can be mathematically modeled (Higle *et al*. 2003, Taha 1975 and Winston 1995).

Objective function:

$$Maximize\ Z = c_1 x_1 + c_2 x_2 + ...+c_n x_n \quad (1)$$

Formulation of constraints:

$$a_{11} x_1 + a_{12} x_2 + ...+ a_{1n} x_n \le b_1 (2)$$
$$a_{21} x_1 + a_{22} x_2 + ...+ a_{2n} x_n \le b_2$$
$$\vdots \qquad \vdots$$
$$a_{m1} x_1 + a_{m2} x_2 + ...+ a_{mn} x_n \le b_m$$
$$x_j \ge 0,\ j= 1,2,3,\ldots\ldots\ldots n$$

where, x_j represent the vector of variables while c and b are vectors of known matrix of coefficient. The expression to be maximized is called the objective function. The equation (2) is the constraint which specifies a convex polytypic over which the objective function is to be optimized. The coefficients c_1, c_2,......c_n are the unit returns coming from each production process x_1 ,x_2 ,x_3, ...x_n.

By converting above general linear programming problem in standard form using slack variable as x_n+1

$$\text{Maximize } Z = \sum c_i x_j \qquad i = 1, 2, 3,.............m$$
$$\text{Subject to} \qquad j = 1, 2, 3,.............m$$
$$\sum A_{ij} x_j + x_n + 1 = b_i$$
$$x_j \ge 0$$

where, Z = The objective function to be maximized, x_j = Input variables, c_i = Cost coefficients of the objective function Z, b_i = Maximum limit of the constraints, A_{ij} = Coefficients of the functional constraint equations.

First of all the inequalities describing the problem were set up and the inequalities were converted into equalities by adding slack variables. The equalities were entered in a table for initial basic feasible solutions with all slack variables as basic variables. Z - c_j values for this solution where calculated c_j is objective function coefficients for variable j and Z represents the decrease in the value of the objective function that will result if one unit of the variable corresponds to the column of a matrix that formed the basis. Determine the entering variable by choosing the one with the highest negative value and also determine the row to be replaced by dividing the quality column by corresponding optimum column values and choosing the smallest positive quotient. Compute the evolutes for the entering rows. Compute values for the remaining rows. Calculate Z – c_j for this solution. If there is positive Z – c_j value, then optimal solution has been obtained otherwise go to next step's optimal solution is obtained when all the entries in Z – c_j, positive or zero.

RESULTS AND DISCUSSION

The long term average monthly climatic data were collected in the Ur watershed. The climate is subtropical with hot dry summer and cold winter. About 80 per cent of the annual rainfall is received during monsoon (June-September) and some rainfall is also received during winter season (December-March). Maximum evapotranspiration rate was observed in months of May and June with relative humidity of about 35 per cent in the morning and less than 18 percent during the afternoon hours.

The reference evapotranspiration was computed using the CROPWAT model developed by FAO using the climatic data, viz. maximum and minimum temperature, wind speed relative humidity and sunshine radiation in the Penman-Monteith equation. The maximum reference evapotranspiration value was observed in the month of May (6.82 mm/day) and minimum value was observed in the month of December (2.44 mm/day). The mean annual rainfall is 1218 mm and same pattern was also followed by effective rainfall. Fig 3 shows the ombrothermic diagram of Bagnouls and Gaussen to emphasize the variation in evapotranspiration, rainfall and effective rainfall during the year of the Ur watershed.

Crop water and irrigation requirement of the individual crop on season wise basis was calculated by CROPWAT model and the results are shown in Fig 4 and 5. The total crop water requirement of *kharif* season was 593 cm and *rabi* season was 421 cm. Whereas, crop water requirement of the paddy crop was observed 142 cm followed by the colocacea (110 cm). Similar trend was also observed in

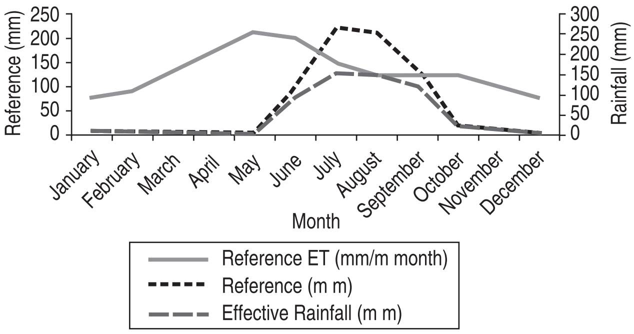

Fig 3 Climatic parameters in UR watershed.

case of irrigation requirement for all the crops in *kharif* season (Fig 4). In *rabi*, highest crop water requirement was observed in wheat crop followed by potato and garlic which is shown in Fig 5. The crops grown during *kharif* season require less irrigation water requirement as much of its consumptive use requirement was satisfied by effective rainfall obtained during monsoon season. Therefore only supplemental irrigation requirements have to be planned for *kharif* crops.

The water availability in the study area for both the crop seasons was found out (Table 2). There was no shortage of water in the *kharif* due to good amount of rainfall during monsoon season but in the *rabi* up to 10% more water was required to fulfill the required demand. Requirement of water available for crops was suggested by LINGO model which was worked out based on the existing collected information of the watershed.

Scenario analysis for kharif season

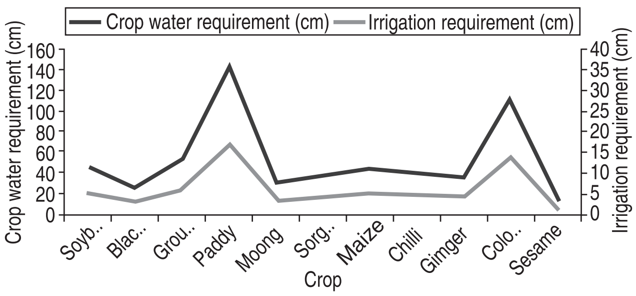

Fig 4 Crop water and irrigation requirement in UR watershed during *kharif* season.

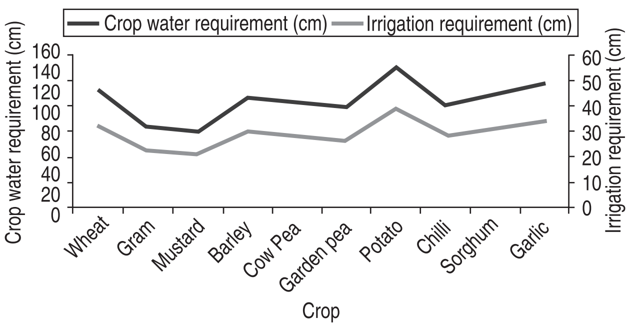

Fig 5 Crop water and irrigation requirement in Ur watershed during *rabi* season.

Table 2 Water availability (in ha-m) in Ur watershed

Source	*kharif* season	*Rabi* season
Rainfall	25775	2148
Ground water	0	272
Ponds and tanks	3256	9617
Total	29031	12037

The Linear Programming model (LINGO) was used for optimum allocation of available land and water for maximizing the net returns from various agriculture crops in the study area. Three scenarios were considered in each crop season, viz. in *kharif* season (1) Existing scenario; (2) Some need based crop scenario; (3) Limitation with cash crop scenario.

Existing scenario: In this scenario, famers used to grow their normal crops with the available existing resources. It was found that blackgram crop was very extensively grown in the watershed because of good market value but after some time due to excessive growing it did not benefit. Sesame, soybean, groundnut and paddy crops were also found in watershed. The net income from the blackgram crop is ₹ 15175/ha which was higher than rest of the cereals and pulses crops. The sesame crop is the second most dominant crop in the *kharif* season with net income (₹ 4260/ha) followed by soybean (₹ 11100/ha) (Table 3). The net income from the other crops is low, but still these are grown in the study area as staple or fodder crops. In recent years, farmers have started growing some of higher income crops, such as chilli, ginger and colocasia.

Need based crop scenario: It was observed that the overall total net income increased after providing some restriction on staple and fodder crops of the watershed. The results showed that chilli, colocasia maize and greengram crops sown area became zero and this area added to the high net return income ginger crop (Table 4). For getting

Table 3 Sown area of *kharif* crops in UR watershed under existing scenario

Crop	Sown area (ha)	Net income (₹/ha)	Yield (kg/ha)	Input cost (₹/ha)	Total net income ((₹ 000)
Soybean	7012	11100	947	15000	77838
Blackgram	18085	15175	732	8000	274440
Groundnut	4388	10240	1502	20000	44933
Paddy	3814	5400	1259	25000	20595
Greengram	1417	3300	512	8000	4677
Sorghum	807	2500	1172	6000	2016
Maize	785	6280	1041	22000	4932
Chilli	1106	390625	8500	62000	432031
Ginger	783	607500	12500	205000	475612
Colocasia	245	240900	19000	160000	58900
Sesame	7491	4260	306	8000	31912
Total	45933				1427886

Table 4 Sown area of *kharif* crops in Ur watershed under some need based crop scenario

Crop	Sown area (ha)	Water requirement (ha-m)	Total net income, (₹ 000)
Blackgram	18085	5389	274440
Ginger	9956	3982	6048270
Soybean	7012	3247	77838
Groundnut	4388	2304	44933
Paddy	3814	5469	20595
Sesame	3000	450	12780
Sorghum	807	283	2016
Chili	0	0	0
Colocasia	0	0	0
Maize	0	0	0
Green gram	0	0	0
Total	47060	21125	6480871

maximum net return from available land and water resources, there is need to plant ginger crop in 9956 ha. Under this scenario, the net return will be 4.94 times higher than the existing scenario.

Limitation with cash crop scenario: In the above two scenarios (Table 3 and 4), there was massive planting of blackgram crop in the area of 18085 ha. But in second scenario (Table 4), ginger crop was planted for maximum net return in the area of 9956 ha. But it was also observed that some time due to excessive availability of the crops in other watershed may reduce the net income of the watershed. That's why in the third scenario, it is suggested that if farmers of the study area grow their normal crops with some cash crops so that they can be benefited more as shown in Table 5. Under this scenario, maximum net return is being reduced up to 0.78 times as compared to scenario 2 but increased by up to 2.5 times as compared to scenario 1.

Table 5 Sown area of *kharif* crops in Ur watershed under Limitation with cash crop scenario

Crop	Sown area, (ha)	Water requirement (ha-m)	Total net income (₹ 000)
Black gram	15085	6984	228915
Soybean	7012	2090	77838
Groundnut	4388	2304	44933
Ginger	4254	1702	2584305
Paddy	3814	5469	20595
Chili	3500	1488	1367188
Colocasia	3000	3366	722700
Sesame	3000	450	12780
Green gram	1417	452	4677
Sorghum	807	283	2016
Maize	783	347	4932
Total	47060	24934	5070879

This scenario suggested more stable and sustainable growth of the watershed because in any situation farmers will not be suffering more.

Scenario analysis for rabi season

Three scenarios were also considered for *rabi* season. (1) Existing scenario with conventional method of wheat growing; (2) Scenario under System of Wheat Intensification; (3) Scenario under increasing 10 % irrigation water.

Existing scenario with conventional methods of wheat growing: In this scenario, farmers grow their normal crops with available resources. It was found that the practising of wheat crop was highest with an area of 29768 ha as followed by gram and mustard (Table 6). The net income of wheat crop is ₹ 11750/ha, which was higher than rest of the cereals crops. The gram was the second most dominant crop in the *rabi* season with net income of ₹ 16640/ha followed by mustard (₹ 12000/ha). The net income of some of the crops was low but still grown in the study area because of staple or fodder crop as shown in (Table 6). In the recent years, farmers have started growing some of the higher net income crops, such as chilli, potato and garlic. The total income in *rabi* season of the watershed was 97.56 lacs.

Scenario under System of Wheat Intensification: In *rabi* season there was shortage of water and farmers used to grow crops like wheat by conventional methods which required more water. Due to shortage of water System of Wheat Intensification was introduced in the watershed. It was observed that after opting for the System of Crop Intensification method for wheat crop (20% water is being saved as compared to the conventional method), total cropped area was increased and same time total income was also increased up to 33% as availability of water for other crops increased (Table 7). After optimizing, it was found that the area of some crops was increased and some crops decreased and even became zero. The area which was decreases added to the highly net return income crops

Table 6 Sown area of *rabi* crops under existing scenario with conventional method of wheat

Crop	Sown area (ha)	Net Income (₹/ha)	Yield kg/ha	Input Cost (₹/ha)	Total Net Income (₹, 000)
Wheat	29768	11750	2080	22000	349773
Chickpea	6862	16640	640	8000	114190
Mustard	3563	12000	585	12000	42755
Barley	1500	5549	1917	8000	8325
CowPea	1107	5500	409	12000	6089
Garden pea	321	6315	3000	70000	2028
Potato	213	86250	17000	156000	18345
Chilli	1106	390625	85000	62000	432031
Sorghum	210	2500	1172	6000	525
Garlic	120	13050	850	32000	1567
Total	44770				975628

Table 7 Sown area of *rabi* crops in Ur watershed under System of Wheat Intensification

Crop	Sown area (ha)	Water requirement (ha-m)	Total net income (₹, 000)
Wheat	29768	11074	349773
Chickpea	6862	1768	114190
Mustard	3563	1069	42755
Chilli	1969	797	769141
Garden pea	321	126	2028
Potato	213	119	18345
Sorghum	210	91	525
Garlic	120	58	1567
Barley	0	0	0
Cowpea	0	0	0
Total	43026	15103	1298324

such as chilli crop. For getting maximum net return from available land and water resources, chilli crop need to be planted in 1969 ha area. Under this scenario, the net return may be 0.33 times higher than the existing scenario.

Scenario under increasing 10 % of irrigation water: It was found that even after using System of Intensification method in wheat crop did cover whole arable land of watershed. That's why model used different combination and indicated that 10% more water was required to bring whole area under cultivation. By this the whole crop area (45738.0 ha) will be covered with irrigation facility. The some of the area which was not previously covered with irrigation and some of the crop shown area became zero such as barley and cowpea, were replaced the high net return giving of chili crop (Table 8). For getting maximum net return from available land and water resources, chilli crop need to be planted in 4681 ha area. Under this scenario, the net return may be 1.42 times higher than the existing scenario.

Table 8 Sown area of *rabi* crops in Ur watershed under increasing 10 % of irrigation water

Crop	Sown area (ha)	Water requirement (ha-m)	Total net income (₹ 000)
Wheat	29768	11074	349773
Chickpea	6862	2168	114190
Chilli	4681	1896	1828516
Mustard	3563	1069	42755
Garden pea	321	126	2028
Potato	213	119	18345
Sorghum	210	91	525
Garlic	120	58	1567
Barley	0	0	0
Cowpea	0	0	0
Total	45738	16602	2357699

Conclusion

In the Ur watershed the planning of agricultural input and maximizing output considered as of the people concern to the farming sector. Quantitative evaluation of hydro-meteorology parameters was carried out in study area for crop water planning purposes. Rainfall was analyzed using CROPWAT model to evaluate the crop water and irrigation requirements. The linear programming model LINGO was used to formulate the problem for maximizing the net return from agricultural field by optimum allocation of available land and water. Multi objective optimization functions were used for maximizing net return under various constraints for *kharif* and *rabi* crop. Three different scenarios were considered for optimization in each crop season. The results showed that in *kharif* season the whole cultivable land is irrigated by the available water in the watershed. But in *rabi* season extra irrigation water is required to fulfill the demand to bring whole area under cultivation. In *kharif* season, all plans suggest, there is a large area (18085 ha) covered by blackgram crop, because the net benefit is more and farmers also find a suitability to grow. In *rabi* season, it was observed that after opting for the System of Crop Intensification method for wheat crop, total cropped area was increased and same time total income was also increased up to 33% as availability of water for the other crops was increased. It was found that if only 10% of irrigation water is increased, the whole crop area (45738.1 ha) is covered with irrigation facility as per recommended scenario 3. In *kharif* season, while comparing third scenario to rest of two scenarios, maximum net return is being reduced up to 0.78 times as compared to scenario 2 but increased by up to 2.5 times as compared to scenario 1. In *rabi* season, while comparing third scenario to rest of two scenarios, maximum net return is being reduced up to 0.33 times as compared to scenario 2 but increased by up to 1.42 times as compared to scenario 1. We need to have a judicious mix of staple food crops (wheat, rice), pulses, millet, vegetables and fodder etc. for maintaining the sustainability of the watershed.

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