

## **Development of an optimal cropping pattern for efficient utilization of land and water resources in the Tons pump canal command area of Eastern Utter Pradesh**

**Sachchida Nand Singh**

**Assistant Professor**

**Department of Agriculture Engineering  
Shri Krishna University, Chhatarpur (M.P.)**

### **ABSTRACT**

The goal of this study was to optimize cropping patterns for the Tons pump canal command of Eastern Uttar Pradesh. The best land was allocated under various crop activities using the linear programming application LINDO-14. The Penman-Monteith equation, 25 years of climatology data and effective rainfall were used to calculate the weekly gross irrigation requirement. The optimal cropping pattern plan was created using the current net discharge from minor irrigation infrastructure, weekly canal discharge, and the gross irrigation demand. The optimization strategy includes total thirteen crops. The optimal crop plans resulted in annual returns of Rs. 232.728, 234.966, and 235.710 Crores which was almost 2.142, 2.162, and 2.169 times the net return under the existing cropping pattern from Plan 1, 2, and 3, respectively. The study also found that one can make greater profits than with the current cropping pattern by using the available canal water and groundwater pumpage at the present rate of optimization.

### **KEYWORDS**

Cropping pattern, Irrigation requirement, linear programming technique, LINDO-14, Net return, Water resources.

### **INTRODUCTION**

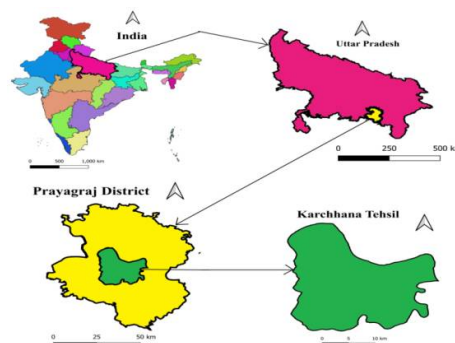
It is well known that water and land are the two most important requirements for human existence, and that water is disappearing at an alarming rate as a result of intensive irrigation systems and fast urbanization. Due to increased demand for land for building development, road construction, industrial use, etc., the amount of land under cultivation is also declining. The world's population today is 8.2 billion. It was 7.1 billion a decade ago. This implies that throughout the last decade, there has been a 1.1 billion rise in the global population. The population is rapidly growing, putting a strain on agricultural land to produce more food to meet the population's needs. This demand on natural resources, i.e. land and water, to increase production reduces soil productivity due to lack of proper supply of nutrients. India is the second most populous nation in the world, accounting for 17.5% of the world's population and with 328 million hectares area, accounting for 2.5 percent of the world's area. As per the growing population and factor associated to it, such as rapid industrial growth, urbanization, and so on, per capita cultivable land is decreasing at an alarming rate. As per this situation, the force on the land to provide for the rising population is increasing.

Irrigation uses two-thirds of the world's fresh water, with groundwater supplies contributing significantly. Groundwater use for irrigation has risen significantly in the previous two decades or so. In our nation, the estimated groundwater capacity is about 350 billion cubic meters, which can be used for commercial, domestic, agricultural, and human consumption, among other things. Due to erratic rainfall and limited access to river water, agricultural water requirements cannot be met only by surface water. Groundwater is a option for meeting agricultural needs but overexploitation should be avoided, as the decrease in groundwater levels in India as well as many other parts of the world, has been critical issue. Large-scale canal irrigation was introduced by the British and continued in independence India, and it was the most commonly used irrigation system at the time because every Indian farmer could not have their own irrigation system. It is challenging to increase the amount of land under cultivation because of urbanization and a reluctance to disturb natural environments. In addition, over the next 15-20 years, the amount of water allocated for irrigation is expected to decrease from its present level. The current cropping pattern, which has been in place for a number of years, does not fully utilize resources for financial gain. As a result, it is essential to maximize production by optimizing available land and water resources. Linear programming models are a helpful tool for supporting optimization process, even if they can handle many constraints. To increase net returns and crop production by utilized existing water and land resources, optimizing water and land resources is important. With the aforementioned factors in mind, the present study was carried out for the Tons Pump Canal Command area of Eastern Uttar Pradesh with the goal of determining the best cropping plan that would yield the highest net return at various water availability levels.

**MATERIALS AND METHODS**

**Details of the study area**

The Tons pump canal command area of Eastern Uttar Pradesh is located in Karchhana Tehsil of Prayagraj district as shown in figure1. The Tons pump canal command area of Karchhana Tehsil lies between 25°09'15" and 25°25'02" N latitude and 81°48'25" and 82°04'45" E longitude. The total geographical area and total Population of the study area is 546.03km<sup>2</sup> and 559088, respectively.

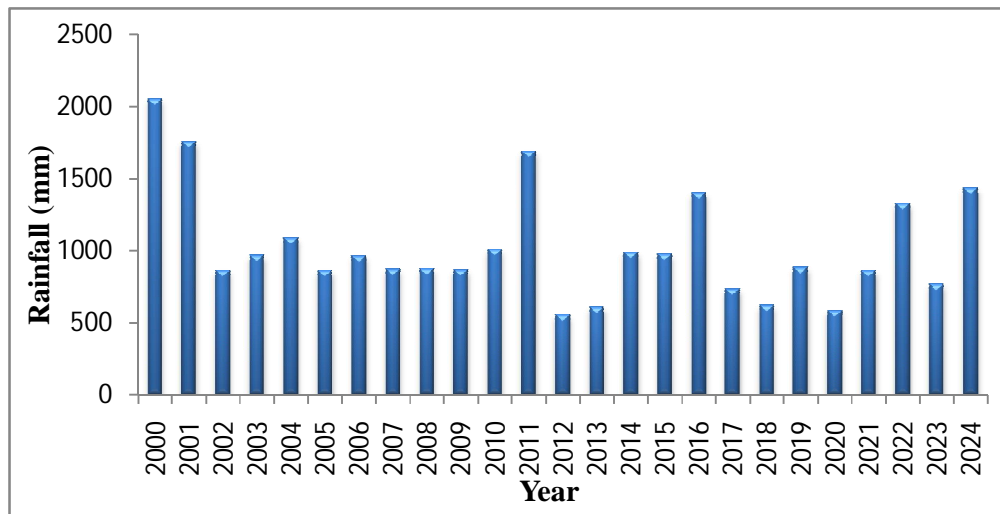


**Figure1. Study area index map.**

**Climate**

The climate of Prayagraj district is humid subtropical. The hot dry summer, chilly dry winter, and hot humid monsoon are its three distinct seasons. The normal rainfall of Prayagraj district is 1027 mm (40.43 inch). The yearly rainfall trend in the study area from 2000 to 2024 is shown in Fig. 2. The average annual temperature is between 26.1 °C (79.0 °F).

During the monsoon period, the relative humidity in the study area ranges from 70% to 80% while it drops at 15% to 20% during the summer period. During the summer, wind speeds were generally high.



**Fig. 2. Yearly rainfall in the study area.**

**Land use**

The area of study has been divided into four categories *i.e.* gross sown area, fallow land, horticultural land, and grass land. Agriculture covered around 62% of the Prayagraj district and 66% of the study area. Wheat, rice, and pearl millet are the study area's principal crops.

**Collection of data**

Meteorological data over a 25-year period (2000-2024) were gathered from Sam Higginbottom University of Agriculture, Technology, and Sciences (SHUATS) Prayagraj's College of Forestry. Department of canal Govindpur, and the Statistical department of Prayagraj provided canal discharge data (weekly) for the year 2024. *Rabi* and *Kharif* are the two primary seasons that dominate farming practices in the canal command area of Tons Pump. In Table 1, the existing agricultural cropping pattern of the previous year (2024) and area beneath various crops is given. From the Prayagraj district of Uttar Pradesh's statistics diary of 2024 gathered the agricultural crop production (Qt/ha), cultivation cost (Rs), and the selling price (per quintal) of each crop grown. Total net returns were computed using this data, as indicated in Table 2. The study area's overall net return from the current cropping pattern was calculated to be Rs. 1086424611.

**Table 1. The study area existing cropping pattern.**

S. No.	Rabi season			S. No.	Kharif season		
	Crop	Area (ha)	Percentage area		Crop	Area (ha)	Percentage Area
1	Wheat	25155	46.07	1	Paddy	15174	27.79
2	Gram	2003	3.67	2	Millet	4879	8.94
3	Potato	846	1.55	3	Arhar	3362	6.16
4	Barley	515	0.94	4	Sorghum	543	0.99
5	Mustard	488	0.89	5	Black Gram ( <i>Urad</i> )	104	0.19
6	Pea	370	0.68	6	Til	11	0.02
7	Sugarcane	197	0.36	7	Sugarcane	197	0.36
<b>Cultivated land</b>		<b>29574</b>	<b>54.16</b>	<b>Cultivated land</b>		<b>24270</b>	<b>44.45</b>
<b>Fallow land</b>		<b>25029</b>	<b>45.84</b>	<b>Fallow land</b>		<b>30333</b>	<b>55.55</b>
<b>Total land</b>		<b>54603</b>	<b>100.00</b>	<b>Total land</b>		<b>54603</b>	<b>100.00</b>

Source: District statistical Dairy (2024) Prayagraj, U.P.

**Table 2. Net return from existing crops of study area.**

Crop	Production Cost (Rs/Kg)	Price of selling (Rs/Kg)	Crop production (Kg/ha)	Crop area (ha)	Net return (Rs/ha)	Total net return (Rs.)
Wheat	11.64	19.75	2998	25155	24314	611613136
Gram	35.00	51.00	1243	2003	19888	39835664
Potato	25.00	12.50	21729	846	217290	183827340
Barley	10.19	16.00	2523	515	14659	7549194
Mustard	28.23	40.50	908	488	11141	5436886
Pea	24.70	32.50	924	370	7207	2666664
Sugarcane	18.00	23.00	49265	197	24633	4852603
Paddy	16.33	18.68	2763	15174	6493	98525541
Millet	12.13	21.50	953	4879	8930	43567567
Arhar	38.86	60.00	1173	3362	24797	83368254
Sorghum	18.25	26.20	689	543	5478	2974310
Urad	38.16	60.00	944	104	20617	2144164
Til	48.71	68.55	29	11	5754	63290
<b>Total net return (Rs)</b>				<b>1086424611</b>		

Source: Uttar Pradesh Statistical Dairy (2024)

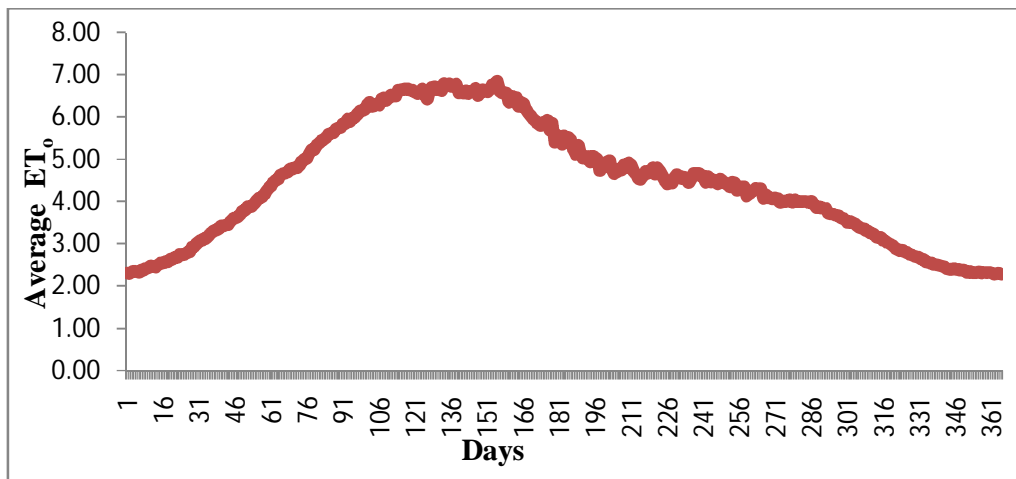
**Estimation of the irrigation needs of different field crops**

By using an MS Excel spreadsheet and Penman-Monteith Equation of the FAO, the Reference Evapotranspiration (ET<sub>o</sub>) was determined. The daily reference evapotranspiration (ET<sub>o</sub>) values were calculated by using each day's maximum and minimum temperature, humidity, sunshine hours, rainfall, and speed of wind. Based on 25 years of climatological data, equation 1 was used to calculate the average daily reference evapotranspiration data and it is graphically represented in Fig. 3.

$$ET_o = \left[ \frac{0.408\Delta(Nr-G) + \gamma \left( \frac{900}{T+273} \right) u_2 (VPD)}{\Delta + \gamma(1+0.34 u_2)} \right] \dots\dots(1)$$

Where,

ET<sub>o</sub>= Reference evapotranspiration in mm day<sup>-1</sup>, Nr= Net radiation (at crop surface) in MJm<sup>-2</sup>day<sup>-1</sup>, G = Heat flux density of soil in MJm<sup>-2</sup>day<sup>-1</sup>, T = Air temperature at 2 metres height in °C, u<sub>2</sub>= Speed of wind at 2 metres height in m s<sup>-1</sup>, e<sub>s</sub>= vapour saturation pressure in kPa, e<sub>a</sub>= vapour actual pressure in kPa, e<sub>s</sub>-e<sub>a</sub>= Deficit vapour saturation pressure in kPa, Δ=vapour pressure slope curve in kPa°C<sup>-1</sup>, Γ = Psychrometric constant in kPa°C<sup>-1</sup>.



**Fig. 3. Variation of estimated daily average reference evapotranspiration, utilising the Penman-Monteith approach (FAO-56).**

FAO-56 provided the crop coefficient (K<sub>c</sub>) value for each stage of crop growth, including the initial, mid-season, late-season, and crop development stages(Pereira *et al.*, 2014). As advised by FAO 56, the K<sub>c</sub> was calculated utilizing the crop coefficient curve approaches. Table 3 lists the number of days, growth season, and stage-wise K<sub>c</sub> value for every crop employed in this study.

Evapotranspiration of each crop was estimated by multiply reference evapotranspiration (ET<sub>o</sub>) mm/day to coefficient of crop (K<sub>c</sub>) (Babu *et al.*, 2015).

$$ET_{crop} = ET_o \times K_c \dots\dots (2)$$

**Table 3. Number of days during the growing period and stage-specific KC value of each crop.**

Crop	Time of sowing	Period of growth stage (days)				Kc		
		Initial	Development	Mid	Last	Initial	Mid	End
Wheat	November	20	25	70	30	0.70	1.15	0.30
Millet	Mid June	15	25	40	25	0.70	1.00	0.30
Paddy	Mid June	30	30	80	40	1.05	1.20	0.90
Barley	November	15	25	50	30	0.30	1.15	0.25
<i>Urad</i>	March	20	30	30	30	0.40	1.05	0.50
Pea	November	15	25	35	15	0.50	1.15	0.30
Gram	Mid October	20	30	30	30	0.40	1.05	0.60
Sorghum	April	20	35	45	30	0.70	1.00	0.55
Potato	Mid October	25	30	30	30	0.50	1.15	0.75
Sugarcane	October	25	70	135	50	0.40	1.25	0.75
Mustard	Mid October	20	40	60	25	0.35	1.00	0.35
<i>Arahar</i>	Mid June	30	25	50	25	0.50	1.00	0.60
<i>Til</i>	July	20	30	40	10	0.35	1.10	0.25

**Effective rainfall**

Effective rainfall was estimated on the basis of Soil Conservation Service Method (USDA) formula. The following formulas are used in analysis:

$$P_E = P(125 - 0.2 P) \times (1/125) \text{ for } P < 250 \text{ mm, and} \dots\dots (3)$$

$$P_E = 125 + 0.1 \times P \text{ for } P > 250 \text{ mm} \dots\dots (4)$$

Where,

$P_E$  = effective rainfall, and  $P$  = total rainfall.

The net irrigation water requirement (NIWR) of each crop was calculated by utilizing field water balance. The formulas utilized in analysis are as following:

$$NIWR = ET_{crop} - (P_E + G_c + W_s) \dots\dots (5)$$

Where,

$ET_{crop}$  = crop evapotranspiration,  $P_E$  = effective rainfall,  $G_c$  = groundwater contribution and  $W_s$  = stored soil water.

Gross irrigation requirement (GIR) refers to the entire amount of water used for irrigation.

$$GIR = (NIWR)/FAE \dots\dots (6)$$

Where,

FAE is the efficiency of field application of the system.

For surface irrigation, field application efficiency and conveyance efficiency values of 70% and 60%, respectively, were selected for the study.

**Water resources**

Besides the rainfall, there are also two primary sources of water available, which is supply of surface water from the *Tons* pump canal and groundwater exploited by minor irrigation systems or other water-lifting devices.

**Canal water availability** -The monthly canal availability of water was computed using the canal command's weekly discharge data.

**Groundwater Draft** - Groundwater was pumped through private and government tube wells, Rahats, open wells, pumping sets on bores, and other water-lifting equipment as part of the minor irrigation units. The guidelines provided by ARDC (1979) were used to calculate the withdrawal of groundwater through irrigation systems as given in Table 4. For the calculation of the groundwater withdrawal through minor irrigation structures, the norms given by ARDC (1979) were followed.

**Table 4: Guidelines of ARDC(1979)**

Type of Well	Season	
	Monsoon	Non-monsoon
Government Tube Wells	4.50	13.50
Private Tube Wells	0.40	1.20
Open Wells	0.18	0.37
Pump Sets on Bore	0.47	0.93
Rahats	0.23	0.69

**Development of optimal cropping pattern modal using the method of linear programming**

LINDO-14 software was used to develop the optimization model with linear programming (LP) technique applied for normal and different probability levels of groundwater condition. The decision or basic variables, objective functions and the model's limitations have been explained as follows.

**Decision variables** - The goal of model is to identify the area that should get irrigation for various crops so as to maximize yearly net benefit and maximum crop production with the available land and water resources. Thus, the irrigated area beneath each crop is a determining factor.

**Objective function** - The area allocation model's goal is to maximise the study area's annual net return (Z1), which was determined as follows(Dahiphale *et al.*, 2015);

Maximize annual net return (Z<sub>1</sub>) =

$$\sum_{i=1}^2 \sum_{j=1}^n NR_i X_i^j, \quad \text{For } i= 1,2,3,\dots,N \quad \dots(7)$$

Where,

$$NR_i = MP_i - CC_i \quad \dots(8)$$

$NR_i$  = Net return from  $i^{th}$  crop in Rs/ha,  $MP_i$  = market price of  $i^{th}$  crop in Rs/quintal,  $CC_i$  = cost of cultivation under  $i^{th}$  crop in Rs/ha,  $Z$  = Total net return from all crops in Rs.,  $Y_i$  = the yield from  $i^{th}$  crop in Quintal/ha,  $N$  = Number of crops,  $X_i$  = Area under  $i^{th}$  crop in ha.

The functions of objectives were attempted to linearity and no negativity constraints (Dahiphale *et al.*, 2015).

**Linearity constraint**

**A. Constraint on cultivable land area** - During any given season, the land allotted to different crops should not surpass the total cultivated area.

$$\sum_{i=1}^n X_i^j \leq A_T \quad I = 1, \dots, n, \quad J = 1, 2, \dots \quad (9)$$

Where,

$A_T$  = Total cultivated area accessible through  $J^{th}$  season in ha, and  $X_i^j$  = Area beneath  $i^{th}$  crop through  $j^{th}$  season in ha.

**B. Constraint on crop area restrictions** - Any crop's allotted area should be less than the maximum amount allowed for that crop.

$$X_i^j \leq A_i^j \text{ max} \quad I = 1, \dots, n, \quad J = 1, 2, \dots \quad (10)$$

**C. Constraint on water requirement** - Every month, the total available water must not be exceeded by the water needed amount for irrigation all the crops.

$$\sum_{i=1}^n TAW_i^m X_i^j \leq CWA^m + GWA^m \quad I = 1, \dots, n, \quad J = 1, m = 1, 2, \dots, 12 \quad \dots (11)$$

Where,

$TAW_i^m$  = Total irrigation water available which is used for crop production in ha-cm during the month  $m$ ,  $CWA^m$ , and  $GWA^m$  = Groundwater and canal water availability from January ( $m = 1$ ) to December ( $m = 12$ ).

**D. Constraint annual net draft of groundwater**- for season  $j$ , the total net draft of groundwater consumption should not above the permitted groundwater extraction for that season.

$$\sum_{i=1}^2 TG^j \leq AG \quad j = 1, \dots, 12 \quad \dots (12)$$

Where,

$AW$  = Permitted seasonal extraction of groundwater in ha-cm.

**Constraints on non-negativity**

According to this requirement, every model decision variable must be non-negative.

$$X_i^j \geq 0 \quad \dots (13)$$

**OPTIMUM CROP PLAN**

**Maximizing net return** - For the linear programming model, total thirteen crops were taken into consideration. For optimal planning, the following crop area restrictions were imposed: wheat  $\leq 13000$  ha, sugarcane  $\geq 0$  ha, mustard  $\geq 0$  ha, paddy  $\geq 10000$  ha, sorghum  $\geq 0$  ha, millet  $\leq 4000$  ha, gram  $\leq 4000$  ha, pea  $\geq 0$  ha, *arhar*  $\leq 8000$  ha, *til*  $\geq 0$  ha, barley  $\leq 1000$  ha, *urad*  $\leq 4000$  ha, and potato  $\leq 7000$  ha,

**RESULTS AND DISCUSSION**

**Sources of available water**

In addition to rainfall, the two primary water sources in the study area which is utilized for irrigation used were surface water deliver from the *Tons* pump canal and groundwater being exploited by minor irrigation structures. The weekly canal water availability was computed using weekly discharge data (Roster map) of the *Tons* pump canal. Based on weekly data, the average monthly net volume water delivered at the field outlet was computed taking conveyance efficiency of the canal as 60%, as shown in Table 5. The groundwater net draft through minor irrigation systems was estimated block wise as discussed in previous section and given in Table 6.

**Table 5. Canal water availability during each month (ha-cm)**

Month	Canal water availability at head (ha-cm)	Canal water availability at field head (ha-cm)
January	1057874.82	634724.89
February	1406389.51	843833.70
March	1057874.82	634724.89
April	0.00	0.00
May	0.00	0.00
June	616537.05	369922.23
July	1254995.41	752997.25
August	946726.89	568036.13
September	1574224.59	944534.76
October	935766.23	561459.74
November	0.00	0.00
December	697029.38	418217.63
<b>Total</b>	<b>9547418.68</b>	<b>5728451.21</b>

**Table 6. Withdrawal of ground water in study area through minor irrigation structures**

Groundwater withdrawal through minor irrigation structures				Gross draft in ha-m	Net draft in ha-m
Government tube wells(ha-m)	Open wells (ha-m)	Bore-based pump sets(ha-m)	Private Tube wells (ha-m)		
6678	228.8	1526	6153.6	<b>14586.4</b>	<b>10210.48</b>

**Irrigation water requirement estimation**

Data on Reference Evapotranspiration ( $ET_0$ ), Crop Evapotranspiration ( $ET_{crop}$ ), Effective Rainfall ( $P_e$ ) and Net Irrigation Water Requirement (NIWR) were essential for the estimate of gross irrigation water requirements of a particular crop. On the basis of these data, gross irrigation requirement were estimate and given in Table 7.

**Table 7. Monthly gross irrigation water requirements of different crops.**

Month	Gross irrigation water requirement (cm)													Total (cm)
	Wheat	Barley	Paddy	Millet	Urard	Pea	Sorghum	Sugarcane	Potato	Mustard	Till	Arhar	Gram	
Jan	9.65	9.65	0.0	0.0	0.00	7.63	0.00	10.63	8.50	8.13	0.0	0.0	5.66	59.85
Feb	13.69	7.80	0.0	0.0	0.00	0.0	0.00	15.14	2.28	10.15	0.0	0.0	0.41	49.47
Mar	11.26	0.0	0.0	0.0	8.74	0.0	6.69	29.51	0.0	2.40	0.0	0.0	0.0	58.60
Apr	0.0	0.0	0.0	0.0	22.50	0.0	22.73	30.88	0.0	0.0	0.0	0.0	0.0	76.11
May	0.0	0.0	0.0	0.0	23.25	0.0	26.52	28.75	0.0	0.0	0.0	0.0	0.0	78.53
Jun	0.0	0.0	1.97	0.0	5.88	0.0	14.07	14.24	0.0	0.0	0.0	0.0	0.0	36.16
Jul	0.0	0.0	0.00	0.0	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
Aug	0.0	0.0	0.00	0.0	0.00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.00
Sep	0.0	0.0	3.07	0.0	0.00	0.0	0.0	0.0	0.0	0.0	1.79	0.62	0.0	5.49
Oct	0.0	0.0	11.39	0.0	0.00	0.0	0.0	2.98	2.96	1.85	1.78	4.31	2.22	27.50
Nov	7.22	3.49	0.00	0.0	0.00	5.50	0.0	6.88	6.98	5.43	0.0	0.00	6.69	42.18
Dec	12.02	11.96	0.00	0.0	0.00	12.26	0.0	11.21	12.59	10.42	0.0	0.00	11.80	82.26
<b>Total</b>	<b>53.84</b>	<b>32.88</b>	<b>16.43</b>	<b>0.00</b>	<b>60.38</b>	<b>25.39</b>	<b>70.02</b>	<b>150.23</b>	<b>33.31</b>	<b>38.38</b>	<b>3.57</b>	<b>4.94</b>	<b>26.79</b>	<b>516.15</b>

**Optimal crop plan for maximizing net returns for the study area by utilizing 60, 80 and 100% of groundwater and available canal water**

The optimal resource usage plan for the study area to maximization of net return under varied crops by using 60%, 80% and 100% of existing groundwater net draft and available canal water is given in Table 8. It can be seen in this table, optimization model allocated crops area according to the minimum or maximum area restrictions set for various crops. During *Rabi* season, allocation the area for wheat, gram, potato and barley crops was same as per maximum limit imposed with all existing net draft levels of groundwater. The area allocation for mustard crop was increased as per maximum limit fixed. There was no any area allocated under pea crop as per minimum limit fixed.

**Table 8. Optimal crop plan by utilizing 60,80 100 percent of groundwater net draft and available canal water for maximizing net returns.**

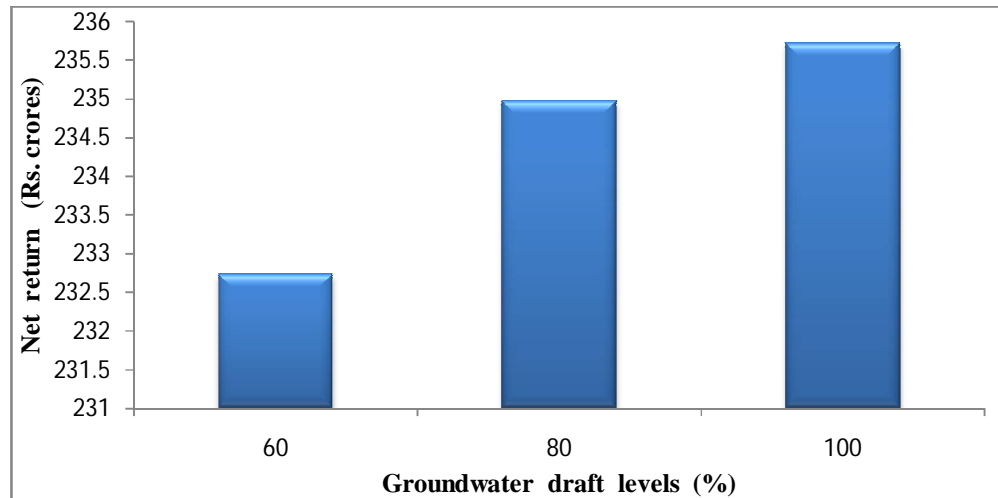
Area allotted for the <i>Rabi</i> season with canal water and varying net draft of groundwater levels (ha)			
Crop	60%	80%	100%
Wheat	13000	13000	13000
Gram	4000	4000	4000
Potato	7000	7000	7000
Barley	1000	1000	1000

Mustard	4574	4282	2650
Pea	0	0	0
Sugarcane	0	292	1924
<b>Cultivated land</b>	<b>29574</b>	<b>29574</b>	<b>29574</b>
<b>Fallow land</b>	<b>25029</b>	<b>25029</b>	<b>25029</b>
<b>Total</b>	<b>54603</b>	<b>54603</b>	<b>54603</b>
<b>Area allotted for the <i>Kharif</i> season with canal water and varying net draft of groundwater levels (ha)</b>			
Paddy	10058	10000	10000
Millet	4000	1978	346
<i>Arhar</i>	8000	8000	8000
Sorghum	0	0	0
<i>Urad</i>	2212	4000	4000
<i>Til</i>	0	0	0
Sugarcane	0	292	1924
<b>Cultivated land</b>	<b>24270</b>	<b>24270</b>	<b>24270</b>
<b>Fallow land</b>	<b>30333</b>	<b>30333</b>	<b>30333</b>
<b>Total</b>	<b>54603</b>	<b>54603</b>	<b>54603</b>
<b>Net return (Rs.)</b>	<b>232.728 Cr.</b>	<b>234.966 Cr.</b>	<b>235.710 Cr.</b>

During *Kharif* season, the area allocation for *arhar* crop was same as per maximum limit imposed with all existing net draft of groundwater levels. The area allocation for paddy crop 10058 ha was increased as per maximum limit fixed with 60% existing net groundwater draft level, however, with 80% and 100% existing net draft of groundwater levels, the allocated area was same as per maximum limit imposed. The area allocation for *Urad* crop 2212 ha was decreased as per maximum limit fixed with 60% existing net groundwater draft level, but, with 80% and 100% existing net draft of groundwater levels, the allocated area was same as per maximum limit set. The area allocation for millet crop was decreased as per minimum limit fixed with increasing existing net groundwater draft level. There was no any area allocated for sorghum and *til* crops as per minimum limit fixed. There was also no any area allocated under sugarcane crop with 60% existing net groundwater draft level, however, increasing in existing net groundwater draft level (80 and 100%), area allocated under sugarcane crop was increased. It was obtained that the annual net return for these plans were Rs.2327287000 or Rs. 232.728 crores, Rs.2349661000 or Rs. 234.966 crores and Rs.2357105000 or Rs. 235.710 crores, respectively.

Fig. 4 shows the difference in the yearly net return with varying groundwater availability levels. The yearly net return from different plans rose as groundwater availability

increased. The findings indicate that it would be advantageous to replace the current cropping pattern with the optimal crop plan. In order to meet the irrigation requirements of crops, there was an excessive amount of groundwater pumping because there was less canal water available.



**Fig. 4. Net return variation under various groundwater availability levels.**

**Conclusions**

The optimal crop plans were developed to maximize net returns for the study area based on the amount of canal water that was available as well as 60%, 80%, and 100% of the groundwater draft by small irrigation infrastructure. By using linear programming model, the best crop plans produced yearly net returns of Rs. 232.728, 234.966, and 235.710 Crores, or almost 2.142, 2.162, and 2.169 times the yearly net return with Plans 1, 2, and 3 under the current cropping pattern, respectively. It was determined that greater profits could be obtained with the available groundwater and canal water at the current rate of optimization than with the current cropping plan. The study came to the conclusion that farmers in the study area would profit from shifting the current cropping pattern in the *Tons* pump Canal Command of Eastern Uttar Pradesh to an optimized cropping pattern.

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