Journal of Pharmacognosy and Phytochemistry
Available online at www.phytojournal.com

E-ISSN: 2278-4136
P-ISSN: 2349-8234
www.phytojournal.com
JPP 2020; 9(2): 530-536
Received: 22-01-2020
Accepted: 26-02-2020

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Optimization of cropping pattern for the Bellan canal command of Urwa block of Allahabad, Uttar Pradesh

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Abstract
The present study was suggesting optimization of cropping patterns for the Bellan canal command of Urwa block, Allahabad, Uttar Pradesh. Linear programming software LINGO-14 was used to allocate optimal area under different crop activities. The weekly gross irrigation demand was estimated using 23 years climatology data and the Penman-Monteith equation as well as effective rainfall. The weekly canal discharge, gross irrigation demand and present net discharge from minor irrigation structures were utilized for cropping pattern plan. Total 13 crops were included in the optimization plan. Three optimal crop plans were developed based on available canal water, and 60%, 80%, and 100% of the existing net draft of groundwater through minor irrigation structures. The annual return of Rs. 979.69, 980.05, and 980.42 lakhs which was about 1.605, 1.606, and 1.607 times of the net return under existing cropping pattern from Plans 1 with 60%, 2 with 80%, 3 with 100% of the existing net draft of groundwater, respectively. The study further concluded that with the use of available canal water and groundwater pumpage at the existing rate of its optimization, one can get 60% more profit than the existing cropping pattern.

Keywords: Irrigation water requirement, cropping pattern, linear programming model, LINGO-14

Introduction
It is well known that water and land are the two basic needs of our society and in which water is decreasing at an alarming rate day by day due to rapid urbanization and intensive irrigation system. The area of land under cultivation is also decreasing due to more requirement of land for the building, road and industry etc. India is the second-largest populated country with over 17.5% of the world's population. According to the 2011 census, the population of India was 128 crores. It is expected that by the year 2022 India would become the world's most populated country, by the year 2050 its population will be reaching about 160 crore (Anonymous, 2015). The world's per capita availability of land in 1993 was 0.28 ha which decreased to 0.24 ha in the year 2007, while per capita availability of water in the year 1993 was 7900 m^3y^{-1} which has decreased to 6600 m^3y^{-1}. According to UN-FAO (Alexandrators and Bruinsma, 2009) an average of per capita availability of cereal for human consumption was 2770 $kcald^{-1}$ during 2005-2007 which is increasing at a rate of 2.1% per year. Hence, the necessity to increase the production together with the optimal utilization of the available land and water resources is of utmost importance.

Agriculture is the main source of food, fiber and fodder. But per capita availability of food, grains, and fuel are declined due to low productivity. We are unable to produce enough food, grains and fiber for our people. We have to improve the overall agricultural product to keep away from these problems. To fulfill the ever-increasing demand of food, fiber and fuel, it is necessary to bring more area under cultivation or increase production per unit area of available land and water resources. Bringing additional area under cultivation is difficult due to urbanization and unwillingness to disturb natural environments. Also, the allocation of water for irrigation will probably decrease over the next 15-20 years.

The existing cropping pattern has been the same from many years and may not utilize resources at the maximum economic benefit. Therefore, it is important to optimize the available land and water resources for achieving maximum production. The demand of these natural resources for the ever-increasing population, It is important to be managed efficiently, optimally and sustainably of these available resources. Keeping in view the need to find a better alternative solution of the problems faced by the farmer, an optimization model was formulated to maximize the net income of farmers at different levels of water availability.

Linear programming model was developed to maximize the net returns of the farmers considering, available land and water resources, crop water requirement and net return from different crops (Yurembam and Kumar, 2015) [6].

The study was undertaken to develop the optimal cropping pattern for maximizing the net returns at a minor level. Keeping the above aspects in view, the present study has been conducted for the Bellan Canal Command of Urwa block of Allahabad district, Uttar Pradesh, with the objectives finding the optimal cropping pattern giving the maximum net return at different water availability levels.

Materials and Methods

Description of the study area

The Bellan Canal command of Urwa block is located in Allahabad district of Uttar Pradesh (Fig. 1). The canals and groundwater are the main sources of irrigation in this area. The Bellan canal system originates from the Meja dam, which is constructed on the Bellan River at Baraundha in Mirzapur district. The study area lies between 24˚48'32" to 25˚ 19'0" N latitude and 81˚44'38" to 82˚19'19" E longitude. There are 66 villages under Urwa block and the total area of the Urwa Block is 17079 ha.

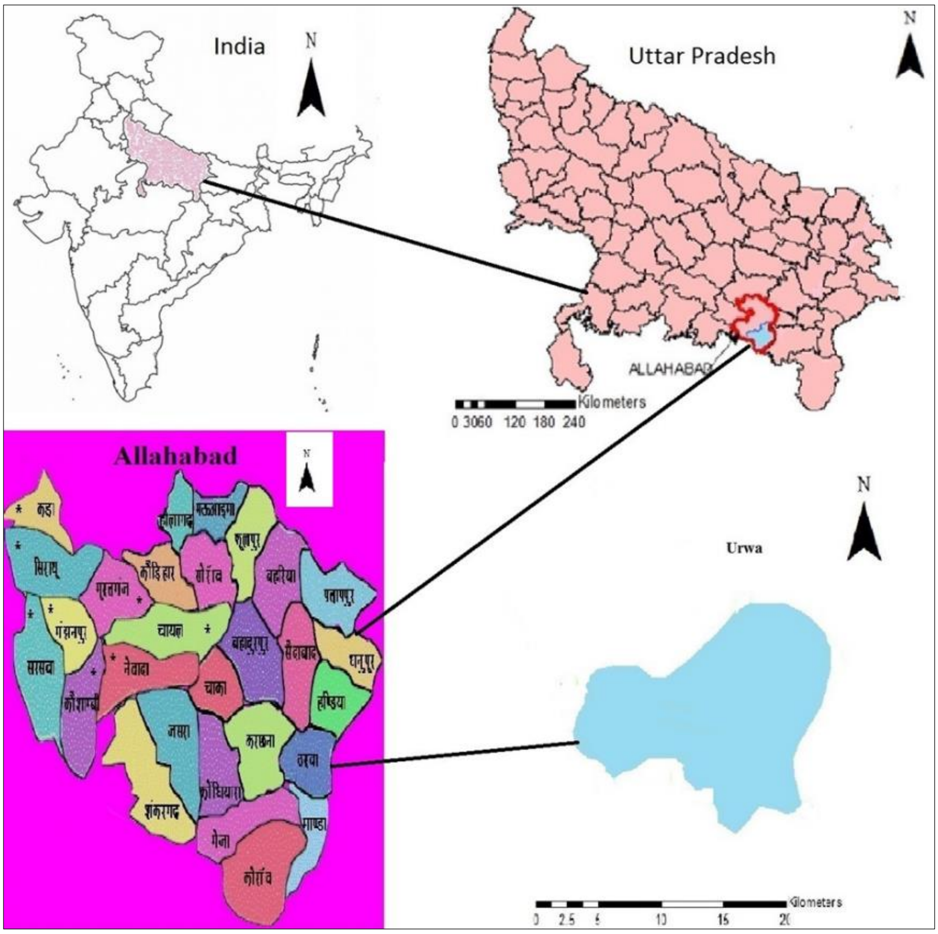

Fig 1: Location of Urwa block

The study area lies in the central plane agro-climatic zone having a humid sub-tropical climate which is characterized by a long and hot summer, fairly pleasant monsoon and winter seasons. The average annual rainfall in the district is about 934 mm but the annual variation is considerable. The time series of annual rainfall in the study area for the period 1994-2016 is shown in Fig. 2. In the summer the mercury rises up to 47 °C whereas in winter it comes down to about 15 °C. The wind speed varied from 2.7 $km.hr^{-1}$ to 8.7 $km.hr^{-1}$, the mean annual speed is about 5.7 $km.ha^{-1}$.

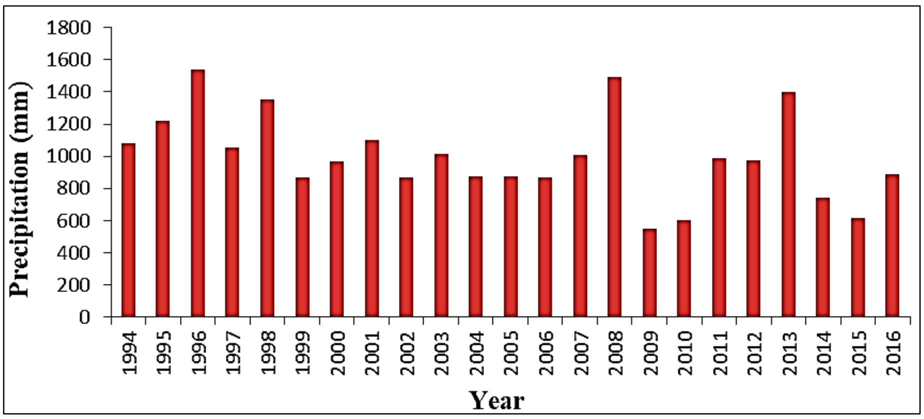

Fig 2: The time series of annual rainfall in the Bellan Canal Command of Urwa block.

Data collection

Meteorological data for 23-year period (from 1994 to 2016) were collected from the College of Forestry, Sam Higginbottom University of Agriculture, Technology and Sciences (SHUATS) Allahabad. Weekly canal discharge data for the period (2016) were collected from Canal Department Govindpur, Allahabad, as well as from the Statistical Department of Allahabad. Agriculture practices in Bellan canal command area of Urwa block revolve around two main seasons namely kharif and rabi. The existing cropping pattern of the year 2015 and area under these crops is given in Table 1. The crop production in quintal per hectare, cost of cultivation and its selling price per quintal of each crop grown in the study area were obtained from the statistical dairy (2016) of Urwa block of Allahabad district, Uttar Pradesh. On the basis of this information, net returns were calculated as shown in Table 2. The total net return of study area from the existing cropping pattern was estimated to be Rs. 61.00 million rupees. The crop production in quintal per hectare, cost of cultivation and its selling price per quintal of each crop grown in the study area were obtained from the statistical diary (2016) of Urwa Block of Allahabad district, Uttar Pradesh. On the basis of this information, net returns were calculated as shown in Table 2. The total net return of study area from the existing cropping pattern was estimated to be Rs. 61 million.

Table 1: Existing cropping pattern of the Bellan Canal Command of Urwa Block

Sl. No.	Crop	Area sown (ha)	Percent area (%)
Rabi season (October-March)			
1	Wheat	6855	40.14
2	Gram	442	2.59
3	Potato	198	1.16
4	Barley	182	1.07
5	Pea	65	0.38
6	Mustard	47	0.28
7	Sugarcane	10	0.06
Fallow Land		9280	54.34
Total		17079	100.00
Kharif season (July-October)			
1	Paddy	4377	25.63
2	Millet	2789	16.33
3	Arhar	880	5.15
4	Sorghum	394	2.31
5	Til	28	0.16
6	Urad	24	0.14
7	Sugarcane	10	0.06
Fallow Land		8577	50.22
Total		17079	100.00

***Source*:** District statistical Dairy (2016) Allahabad U.P

Table 2: Net return from main crops in the Bellan Canal Command of Urwa block

Crop	Cost of production (Rs./Quintal)	Selling price (Rs./Quintal)	Crop production (Quintal/ha)	Area under each crop (ha)	Net return (Million rupees)	Net return (Rs/ha)
Wheat	1550	1625	23.2	6855	11.93	1740.8
Mustard	3550	3700	8.6	47	00.06	1290.0
Sugarcane	250	311	682.9	10	00.42	41656.3
Paddy	1830	1950	25.4	4377	13.36	3051.6
Sorghum	1050	1680	8.7	394	2.17	5506.2
Millet	1400	1430	9.2	2789	00.77	277.2
Gram	6050	7400	7.3	442	4.37	9882.0
Pea	3200	4500	11.1	65	00.94	14482.0
Arhar	6200	7400	11.3	880	11.97	13608.0
Til	6500	7575	2.1	28	00.06	2246.8
Barley	1750	1850	28.3	182	00.52	2837.0
Potato	848	1300	156.7	198	14.02	70832.9
Urd	6800	9300	6.8	24	00.41	16875.0
Total	40978	50021	981.8	16291	61.00	184285.7

***Source*;** Statistical Dairy Govt. of U.P

Estimation of irrigation water requirement

In this study, the reference evapotranspiration was estimated using Microsoft Office Excel worksheet with the help of FAO Penman-Monteith Equation (Allen *et al.*, 1998) [3]. The daily reference evapotranspiration (ET_o) values were estimated using daily minimum and maximum temperature and humidity, sunshine hours, rainfall and wind speed. The daily average reference evapotranspiration values were calculated from Equation 1, On the basis of 23-year climatological data.

$$ET_o = \left[\frac{0.408\Delta(Rn\text{-}G)+\gamma\left(\frac{900}{T+273}\right)u_2(VPD)}{\Delta+\gamma(1+0.34\,u_2)}\right] \quad \ldots\ldots\ldots.. (1)$$

Where

ET_o= reference evapotranspiration [mm day-1], Rn= net radiation at the crop surface[MJm-2day-1], G = soil heat flux density[MJm-2day-1], nT = airtemperatureat 2m height [°C], u2 = wind speed at 2 m height [m s-1], e_s= saturation vapour pressure[kPa], e_a= actual vapour pressure[kPa], e_s-e_a= saturation vapour pressure deficit [kPa], Δ= slope vapour pressure curve[kPa°C-1], γ= psychrometric constant [kPa°C-1].

The crop coefficient values available for every crop growth stage, i.e. initial, crop development, mid-season and late-season stage, were taken from FAO,-56 (Allen *et al*., 1998) [3]. The Crop evapotranspiration was calculated by using the crop coefficient curve as recommended by FAO 56. The number of days for each crop, growing period and stage-wise corresponding K_c value for each crop used for this study is given in Table 3.

Crop evapotranspiration (ET_{crop}) was calculated by multiplying reference evapotranspiration (ET_o, mm day^{-1}), with a crop coefficient (K_c).

$ET_{crop}=ET_o \times K_c$ ….(2)

Table 3: Number of days for each crop growing period and stage-wise corresponding KC value for each crop.

Crop	Date of sowing	Growth stage period (days)				Total	Kc Ini	Kc Mid	Kc End
		Initial	Development	Mid	Last				
Wheat	November	20	25	60	30	135	0.7	1.15	0.3
Paddy	Mid June	30	30	60	30	150	1.05	1.2	0.9
Millet	Mid June	15	25	40	25	105	0.7	1	0.3
Barley	November	15	25	50	30	120	0.3	1.15	0.25
Urad	March	20	30	30	30	110	0.4	1.05	0.5
Pea	November	15	25	35	15	90	0.5	1.15	0.3
Gram	Mid October	20	30	30	30	110	0.4	1.05	0.6
Sorghum	April	20	35	45	30	130	0.7	1	0.55
Potato	Mid October	25	30	30	30	115	0.5	1.15	0.75
Sugarcane	October	25	70	135	50	280	0.4	1.25	0.75
Mustard	Mid October	20	40	60	25	145	0.35	1	0.35
Arhar	Mid June	30	25	50	25	130	0.5	1	0.6
Til	July	20	30	40	10	100	0.35	1.1	0.25

Effective rainfall

The effective rainfall was calculated according to USDA Soil Conservation Service Method. The formula used in the analysis was as following:

$P_{eff} = P_t (125-0.2 P_t)*(1/125)$ for $P_t < 250$ mm, and …. (3)
$P_{eff} = 125 + 0.1\times P_t$ for $P_t > 250$ mm …. (4)

Where;
P_{eff}= effective rainfall, and P_t= total rainfall.

The net irrigation requirement of the crop is estimated using the field water balance.

NIWR = ET crop – ($P_e + G_e + W_b$) …. (5)

Where, ET_{crop} = Crop evapotranspiration n, P_{eff}= effective rainfall, G_e= groundwater contribution, and W_b= stored soil water. Considering no change in stored soil water (W_b) before and after the crop duration and there is no contribution of groundwater (G_e).

NIWR = ET crop – P_e …. (6)

The total amount of water applied through irrigation is termed as 'gross' irrigation requirement (GIR).

GIR = (NIWR)/FAE …. (7)

Values of conveyance efficiency and field application efficiency (FAE) for surface irrigation were taken for the study as 60% and 70% respectively (ICID, 1967; Irrigation commission, 1972).

On the basis of weekly discharge data of the canal command, the monthly canal water availability was calculated.

Groundwater Draft

The groundwater withdrawal through minor irrigation units included pumpage of groundwater through Government and private tube wells, open wells, Rahats, pumping sets on bore and other water-lifting devices. For the calculation of the groundwater withdrawal through minor irrigation structures, the norms given by ARDC (1979) were followed.

Table 4: Norms of (ARDC, 1979)

Type of the Well	Season		
	Monsoon	Non-monsoon	Annual
Government Tube Wells	4.5	13.5	18
Private Tube Wells	0.4	1.2	1.6
Open Wells	0.18	0.37	0.55
Rahats	0.23	0.69	0.92
Pump Sets on Bore	0.47	0.93	1.4

Development of Model using Linear Programming Technique

The optimization model was developed to optimize the extent of cropped areas for normal rainfall conditions using a linear programming technique. The optimization model was solved using LINGO 14 software (Singh *et al*., 2001) [5]. The objective function and constraints of the model have been described as follows.

The purpose of the model was to determine the area to be irrigated under different crops to obtain maximum benefits with the available land and water resources. Hence, the area irrigated under different crops as the decision variables.

Model formulation

The objective function of area allocation model is to maximize the net return from the command area, is calculated as below

Maximize $Z = \sum C_i X_i$, for i= 1, 2, 3……n ……(8)

Where

Z = is the total net return from all the crop (Rs.), N = the number of crops, C_i = the net return from i^{th} crop (Rs. ha^{-1}), X_i = is the area under i^{th} crop (ha), a decision variable.

The objectives function has been subjected to linearity and no negativity constraints.

Linearity constraints

A. Cultivable land area constraint: The land allocated to different crops in any season should not exceed the total cultivable land area.

$$\sum_{i=1}^{n} X_i^j \leq A_T \qquad i=1......n, j=1, 2 \qquad .... (9)$$

Where

A_T = total cultivable area available during j^{th} season in the command (ha) and X_i^j = area under i^{th} crop during j^{th} season (ha).

B. Crop area restriction Constraints: The area allocated to a crop should be less than the maximum area allotted for that crop. The criteria to allocate the maximum area for each crop were fixed as per the annual food requirement for the population of the study area.

$$X_i^j \leq A_i^j{}_{max} \quad i = 1....n, j=1, 2 \qquad .... (10)$$

C. Water requirement constraints: The irrigation water requirement of all the crops in any month should not greater than the total water available.

$$\sum_{i=1}^{n} W_i^k X_i^j \leq CW^k + GW^k \quad i=1...n, j=1, k=1....12 \qquad .... (11)$$

Where

W_i^k = total irrigation water used for the production of crop i (ha-cm) during month k, CW^k and GW^k = canal water availability and groundwater availability during month k = 1 for January to 12 for December.

D. Annual groundwater draft constraint: The total draft use in season j should not exceed the allowable groundwater extraction in the season j.

$$\sum_{j=1}^{2} GW^j \leq AGW \qquad j=1.....12 \qquad .... (12)$$

Where

AGW = allowable seasonal groundwater extraction (ha-cm) in the command.

Non-negativity constraints: This restriction states that all decision variables of the model should be non-negative.

$$X_i^j \geq 0 \qquad .... (13)$$

Maximum crop area limits

The restrictions for the maximum area of crops to be grown in the study area were estimated on the basis of food requirement for population 203637 of the study area. The oil recovery from mustard was taken as 33% and sugar recovery as 104.23 $kg.t^{-1}$ of sugarcane. There required area under pulses crop are 2406.06 ha, which distributed between pulses crops as per the existing cropping pattern area (gram 745 ha, pea 96 ha, arhar 1492 ha and urad 41 ha). As per the existing cropping pattern, the area under til crop was 28 ha. Keeping it in view, the maximum area under til crop is fixed at 50 ha. Crop name, annual food requirement of a common man (kg), total annual food requirement for the population of the study area (Quintal), production (Quintal/ha), required cultivation area for production to fulfill food requirement (ha) are given in Table 5.

Optimal crop plans

A linear programming model, using LINGO-14 with an objective to maximize the net return from the study area, was developed to allocate the land area under different crops. Total thirteen crops were considered for the linear programming model. Therefore, optimal crop plans for the study area have been developed on the basis of available canal water and 60, 80, and 100% of the existing net groundwater draft through minor irrigation structures. There are fix the maximum cultivated area under every crop except mustard for every plane as per the annual food requirement of a common man. Therefore, for the optimization planning, these area limit for wheat ≤4676 ha, mustard ≥0 ha, sugarcane ≤372 ha, paddy ≤6350 ha, sorghum ≤850ha, millet ≤2358 ha, gram ≤745 ha, pea ≤96 ha, arhar ≤1492 ha, til ≤50 ha, barley ≤93 ha, potato ≤312 ha and urad ≤ 41 ha.

Table 5: Crop name, annual food requirement of a common man (kg), total annual food requirement for the population of the study area (Quintal), production (Quintal/ha), required cultivation area for production to fulfill food requirement (ha)

Crop name	Annual food requirement of a common man (kg)	Total annual food requirement for population of the study area (Quintal)	Production (Quintal/ha)	Required cultivation area for production to fulfill food requirement (ha)
Wheat	53.30	108538.14	23.21	4678.00
Rice	79.30	161484.14	25.43	6350.14
Barley	1.30	2647.28	28.30	93.31
Millet	10.70	21789.15	9.24	2358.13
Potato	24.00	48872.00	156.71	311.86
Mustard oil	1.60	325819.20	8.60	1148.05
Sugar	19.00	2688008.40	682.89	372.31
Pulses	13.40	27287.35	11.34	2406.60

***Source*:** Annual food requirement of a common man (Bajaj and Srinivas, 1989), Production (Statistical Diary of Uttar Pradesh Government)

Results and Discussion

Available water resources

The study of the canal water availability showed that the maximum weekly water supply through the canal at the field outlet was 327.94 ha-m, while the maximum monthly available water at field outlet was 983.81 ha-m in March. The net draft of groundwater from minor irrigation structures was calculated 2858.24 ha-m for the year 2015 as discussed in Table 6. Month wise water availability for the year 2015 in the Bellan Canal Command is given in Table 7.

Table 6: Groundwater withdrawal through minor irrigation structures in the Urwa Block for the year 2015.

Block	Groundwater withdrawal through					Gross draft (ha-m)	Net draft (ha-m)
	Govt. tube wells (ha-m)	Open wells (ha-m)	Rahats (ha-m)	Pump sets on Bore (ha-m)	Private Tube wells (ha-m)		
Urwa	2754	22	0	147.2	1160	4083.2	2858.24

Table 7: Monthly canal water availability for the year 2015 in Bellan Canal Command of Urwa block (ha-cm).

Month	Water available (ha-cm)
January	109312
February	54656
March	163968
April	0
May	0
June	54656
July	109312
August	109312
September	109312
October	109312
November	0
December	109312

Source: Bellan canal division Govindpur, Allahabad.

Irrigation water requirement

The estimated net irrigation requirement of the crop is given in Table 8.

Table 8: Net irrigation requirement of crop

Crop	Net depth of Irrigation (cm)
Wheat	33.66
Mustard	35.22
Sugarcane	149.65
Paddy	35.94
Sorghum	56.93
Millet	0.67
Gram	25.55
Pea	28.47
Arahar	3.66
Til	2.87
Baraley	33.66
Potato	31.92
Urd	60.94

Optimization of crop planning for the Bellan Canal Command of Urwa block

The net return in lakhs and area in ha allocated under each crop for Rabi and Kharif season for all three plans with 60, 80, and 100% of the existing net groundwater draft through minor irrigation structures are given in Table 9.

Table 9: Net return and area allocated under crop with canal water and different levels of net groundwater draft for the Rabi and Kharif season.

Crop	Area allocated with canal water and different levels of net groundwater draft (ha) for Rabi season		
	60%	80%	100%
Wheat	4676	4676	4676
Mustard	16	44	72
Sugarcane	372	372	372
Gram	745	745	745
Pea	96	96	96
Barley	93	93	93
Potato	312	312	312
Total allocated area	6310	6338	6366
Fallow	10769	10741	10713
Total	17079	17079	17079
Area allocated with canal water and different levels of net groundwater draft (ha) for Kharif season			
Paddy	5748	5748	5748
Sorghum	850	850	850
Sugarcane	372	372	372
Millet	0	0	0
Arhar	1492	1492	1492
Til	0	0	0
Urad	40	40	40

Total allocated area	8502	8502	8502
Fallow	8577	8577	8577
Total	17079	17079	17079
Net return (Rs. Lakhs)	979.69	980.05	980.42

The area allocated under mustard crop 16, 44 and 72 ha at 60, 80, and 100% of net groundwater draft levels. The area under mustard crop increased with the increase in groundwater draft. The area under millet and til crop allocated zero at all groundwater draft levels. The area under wheat, sugarcane, gram, pea, barley, potato, sugarcane, arhar and urad is the same at every groundwater draft levels. The area allocated of wheat, gram, pea, barley and potato crop of rabi season reached at the maximum fixed area as provided in the model and during kharif season the area allocated of sorghum and arhar reached at the maximum fixed area as provided in the model. For rabi season total available cultivated land was 7799 ha. None of the scenarios of this season reached this limit due to maximum crop area limits. For kharif season total available cultivated land was 8502 ha. The entire scenario of this season reached this limit due to water availability. The variation in net return with different levels of net groundwater draft is shown in Figure 3. The annual net return from different plans increased with the increase in the net groundwater draft.

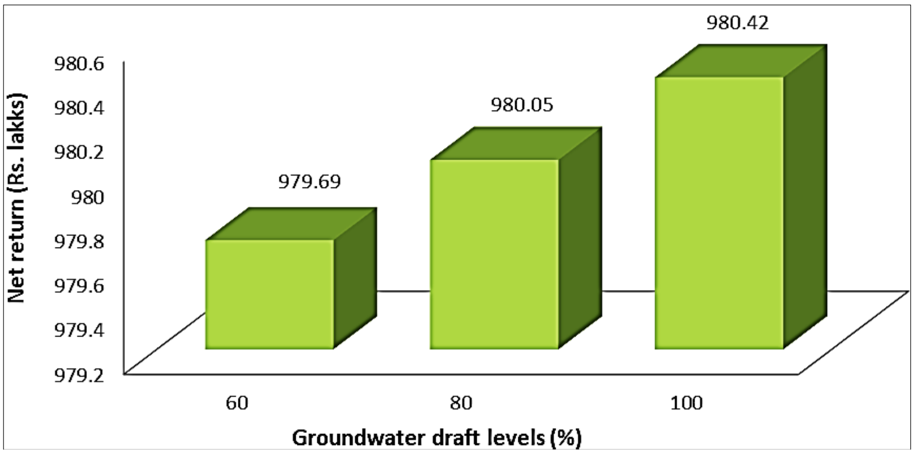

Fig 3: Variation of net return under different levels of net draft of groundwater.

Conclusions

The optimal crop plans for the study area were developed on the basis of available canal water, and 60, 80 and 100% of the existing net draft of groundwater through minor irrigation structures. The maximum area under every crop was fixed except mustard in the all three plan, as per the annual food consumption requirement for the population of the study area. The optimal crop plans, using linear programming, resulted in the annual return of Rs. 979.69, 980.05 and 980.42 lakhs which was about 1.605, 1.606, and 1.607 times of the net return under existing cropping pattern from Plans 1, 2 and 3, respectively. It was concluded that with the use of available canal water and groundwater at the existing rate of its optimization can get 60% more profit than with the existing cropping pattern. The study concluded that replacing the existing cropping pattern in the Bellan Canal Command of Urwa block by optimization cropping pattern would be profitable to the farmers of the study area.

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