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Optimal crop planning for conjunctive use of irrigation water in Punjab: A path towards sustainable development

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Abstract
In the present study, an attempt has been made to develop optimum crop planning strategies to increase the productivity with minimum input cost, maximising net returns and significant savings of groundwater under the constraints of available resources like irrigation water, land and fertilizers etc. for Punjab state by using linear programming technique. The optimum crop model with existing water use conditions resulted that there will be net gain of Rs. 680 crores, Rs. 650 crores and Rs 17 crores at market prices, economic prices and natural resource valuation prices respectively. The results revealed that with 10 per cent reduction in current irrigation wateruse, the profit would decrease by 3.52 per cent, 3.53 per cent and 3.60 per cent respectively at the respective prices. The optimum crop model exhibited decline in gross cropped area by about 3 per cent each at all the prices and net loss was estimated of Rs. 989 crores, Rs. 740 crores and Rs. 1302 crores at market, economic and natural resource prices respectively. Whereas by using 80 per cent of current irrigation water usage in Punjab state there will be decrease in gross cropped area by 13.95 per cent, 12.98 per cent and 12.97 per cent at market prices, economic prices and NRV prices respectivelycausing net loss of Rs. 4047 crores, Rs. 3171 crores and Rs. 3682 crores at the respective prices. Thus, the study brought out that there is trade-off between water saving and profitability from the crops i.e. if water is to be saved, profits of the farmers would decline. Further, it was revealed that the efficiency of irrigation water could be increased by using water saving technologies such as laser land leveller and tensiometer etc.

Keywords: optimum crop plan, linear programming, groundwater use, cost of cultivation

Introduction

Irrigated agriculture is the dominant global user of fresh water, accounting for nearly 70 per cent of consumptive use (Aeschbach H and Gleeson 2012) [1]. In many parts of the world, increasing demand for irrigation as well as extensive subsidies and limited regulation are placing increasing stress on fresh water resources (Postal *et al*., 1996, Vorosmarty *et al.*, 2000, Haddeland *et al.*, 2014) [16]. To maintain agricultural productivity while reducing pressure on these resources, large increases in water use efficiency (the economic value produced per unit of the resource) will be required (Gleick, 2003) which can be brought about through the use of water efficient cultivation technologies. Globally about 40 per cent of irrigation water is supplied from groundwater and India is the world's largest user (Aeschbach H and Gleeson, 2012) [1]**.** In India, groundwater irrigation covers more than half of the total irrigated area and is responsible for 70 per cent of production and supports some 50 per cent of the population (World Bank 1998 and Shah, 2010) [17, 14]. However, it is now becoming clear that over extraction of ground water is depleting aquifers across the country and water table declines are pervasive. In fact, the rates of depletion in India are probably the highest in the world (Aeschbach H and Gleeson 2012) [1].

Punjab state, one of the smallest states of India having only 1.5 per cent of the geographical area of the country, is pre-dominantly an agrarian state contributing around two third of the food grains produced annually in the country. Nearly 83 per cent of the land in Punjab is under agriculture compared to the national average of 43 per cent. Cropping intensity has increased from 133 percent in 1971 to 190 percent in 2009.The state has 86 percent cropped area and 98 percent of this is under irrigation that uses nearly 84 percent of the state's water resources out of this, rice consumes 34 percent, wheat 30 percent and other crops 36 percent (Jain, 2012) [10]. Agriculture in the state is highly intensive having heavy requirement of water for irrigation. The economy and wellbeing of the farmers depend largely on the availability of water. The hard work of the farmers has proudly earned the State the name of "Food Basket of Country". Surface water resources are being fully managed through well-organized canal irrigation system. The available surface water resources of the state are fully committed and unable to meet further demand of water in irrigation for agriculture; as such increasing pressure on ground water resources. The groundwater is being exploited exceeding to limit at annual recharge to meet increasing demand of water for diverse purposes i.e. intensive irrigation, industry, power generation etc. Injudicious utilization and excessive reliance on this precious natural resource in the state has resulted into emergence of groundwater crisis and the state stands at an extreme end of overexploitation of ground water (Singh *et al*., 2017 and Shah, 2010) [14]. The scenario of falling water table is threatening the sustainability of agriculture in this food bowl of India. One of the major concerns often voiced is the increase in the area under paddy, the major water consuming crop. The paddy area occupying less than 0.4 million ha (mha) in 1980 increased to 2.8 mha in 2017. Due to this depletion in groundwater resources irrigation expenditure for paddy and wheat crops has increased manifold in the last decade. The increased cost of deepening the well and pump replacement (from centrifugal to submersible) has contributed to increasing incidence of farmer's indebtedness (Kaur B *et al*., 2015, Kaur S and Vatta K, 2015) [11, 12]. The consequences of over pumping of groundwater has been elucidated by various scholars (Shah, 2010, Singh*et al*., 2017 and Srivastava *et al*., 2014) [14, 15]. The groundwater use in the agriculture can be reduced by curtailingexcessive withdrawal as well as by improving water use efficiency in crop production. In the backdrop of this, the study therefore attempts to (i) examine the status of water resources and crop wise groundwater usage in Punjab and (ii) to suggest optimal cropping pattern for maximizing net returns and ensuring significant savings of groundwater with the aim of sustaining groundwater use in Punjab agriculture.

Methodology

The study is primarily based on plot-level data collected under "Comprehensive Scheme for Cost of Cultivation of Principal Crops" of the Directorate of Economics and Statistics (DES), Ministry of Agriculture, Government of India.. In the Cost of Cultivation Scheme (CCS), each sample household is surveyed consecutively for three years and the latest available data pertain to the period 2008-09 to 2010-11, thus, data were collected from the 300 representative households of 30 tehsils of Punjab state.. From three agro-climatic zones of the state, farmers were selected using three-stage stratified sampling technique, with tehsil as stage one, a village or cluster of villages as stage two and operational holdings within the cluster as stage three. From each cluster, a sample of 10 operational holdings, two each from the five size-classes, *viz*. marginal (< 1 ha), small (1-2 ha), semi-medium (2-4 ha), medium (4-6 ha) and large (> 6 ha), were selected randomly.

Secondary data have been gathered from various sources such as Punjab State Electicity Regulatory Commission, Central Ground Water Board (CGWB), Central Water Commission (CWC), Statistical Abstract of Punjab (Various issues) to meet the stipulated objectives of the study.

Optimization of crop model

The Mathematical Programming can be used for developing optimum crop or land use planning. It is an easy and flexible method for assessing different ways to use limited resources under variable objectives and constraints. The present study makes an attempt to develop different crop planning strategies by using *linear programming* (LP). It develops the crop model which increases the productivity with minimum input cost under the constraints of available resources like irrigation water, land, human labour, fertilizers, seeds, etc., and ultimately getting maximum net benefits. Multi-crop model for two seasons were formulated in LP for maximizing the net returns, minimizing the cost and minimizing the water usage by keeping all other available resources (such as cultivable land, seeds, fertilizers, human labour, pesticides, capital etc.) as constraints.

Mathematical specifications of the model

Mathematically, model specification for Punjab are presented by Equations 1-6 followed by equation wise description.

$$MaxZ = \sum_{C=1}^{n} (y_{cP_c - C_c)\,A_c} \quad (1)$$

$$\sum_t \sum_c a_{tc} A_c \leq NS_t OA_t \quad (2)$$

$$A_c \geq min_c \quad (3)$$

$$A_c \leq max_c \quad (4)$$

$$\sum_c \quad w_c A_c \leq RGWAA \quad (5)$$

$$A_c \geq \; 0 \quad (6)$$

Objective Function: Maximization of net income

$$\sum_{c=1}^{n} (y_{cP_c - C_c)\,A_c}$$

Let Yc denotes yield of a crop *c* in one hectare of land, *P* the price received for the output from crop c, *Cc* refers to the cost incurred to cultivate crop c in one hectare of land and Ac is the area under cultivation of crop c then the RHS of the Equation 1 represents sum of net revenue obtained from all the crops considered for the optimum model development. The objective is to maximize the net revenue (z) based on the optimum crop plan.

Land Constraint

Optimum use of land for each month is required. This can be achieved by having separate constraint equation (Equation 2 is a compact form of 12 equations one for each month as shown below).This helps to have separate sown area for each month and ensures that total cultivated area underselected crops in each month should be less than net sown area (NS_t) minus area under orchard (OA_t)crops. Further crop calendar has to be maintained as per format in Appendix 1 (Crop calendar for Punjab).Thus, a_{tc} in equation 2 refers to the coefficient of crop calendar matrix for t^{th} month and c^{th} crop.

$$\sum_c a_{Jan\,c} A_c \leq NS_{Jan} - OA_{Jan} \text{ To } \sum_c a_{Dec\,c} A_c \leq NS_{Dec} - OA_{Dec}$$

$$\sum_t \sum_c a_{tc} A_c \leq NS_t OA_t$$

Minimum and maximum constraints

Generally, crop planning model using LP primarily captures the supply side behaviour specifically area response based on net returns and resource constraints ignoring the demand aspect. Such models tend to over-estimate or under-estimate the area allocations for some crops. As a consequence, a single crop may cover infeasible larger area (over-estimation) or null or negligible area (under-estimation).

In some modelling solutions, some major crops may drastically lose their relevance and the corresponding area allocations may become negligible. Then, even though estimates are robust and mathematically proven, such allocations may not be desirable and practically possible from the view point of food security of the country and livelihood security of the farmer because appropriate changes are required in policy framework of the country to adopt the optimum sustainable model. Similarly, area allocations for some minor crops may be over-estimated ignoring the demand. Such an area allocation is again undesirable as it may lead to glut in the market. To avoid such undesirable over-estimation or under-estimation, assigning values to minimum and maximum area of the selected crops become essential in the model.

Ground water constraints

Water is a scarce natural resource. The ground water usage should be less than or equal to Replenishable Ground Water Available for Agriculture (RGWAA) for making the agriculture sustainable.

Data of RGWAA is published by Central Ground Water Board. RGWAA can be estimated by deducting water consumed by industries and other non-farm sectors from total replenishable ground water.

Ground water constraint to be used in Linear Programming (LP) model for Punjab agriculture is as follows.

$$\sum_c \quad w_c A_c \leq RGWAA \qquad (5)$$

Where w_c is actual water drafted for a crop c in recent years based on Cost of Cultivationdata. A_c refers to the area allocation for a crop c.

For the Punjab state, different scenarios have been developed by using different values of RGWAA *e.g.* (1) unlimited use of water by not using the water constraint, (2) Water restricted to 90 per cent of current water use and (3) Water restricted to 80 per cent of current water use

Comparing Net Returns under alternative scenarios

Net returns at market prices

Net returns at market prices were computed as the gross returns (value of main product and by product) less variable costs (Cost A_1 + imputed value of family labour) at market prices actually paid and received by the farmer or imputed in some cases.

$$NR_{MP} = GR - VC \qquad (i)$$

Where, NR_{MP} – Net returns at market prices; GR- Gross Returns; and VC- Variable Costs

The imputed value of family labour has been calculated as:

$$\textit{Imputed value of family labour} = \textit{Working hours of family labour} \times \textit{Labour wage rate per hour}$$

Net returns at Economic prices

Net returns at economic prices (NR_{EP}) were computed as the difference between net return or income at market prices and subsidies on inputs like fertilizers and irrigation used in crop production.

$$\text{I.e. } NR_{EP} = NR_{MP} - \text{Subsidy} \qquad (ii)$$

Thus, subsidy component has internalized into the model, by covering two aspects *viz.*, fertilizer subsidy and irrigation subsidy. Fertilizer subsidy consists of subsidy on nitrogen (N) and combination of Phosphorous (P) and Potassium (K). The total irrigation subsidy includes canal, electricity and diesel subsidy and has been distributed over selected crops based on area under irrigation of each crop.

Income based on Natural Resource Valuation technique

Net returns based on Natural Resource Valuation (NRV) technique were computed by adding value of nitrogen fixation by legume crops at economic price of nitrogen (Value of N) and deducting the imputed value of increase in GHG emission cost to the atmosphere.

$$\text{I.e. } NR_{NRV} = NR_{EP} + (\text{Value of N} - \text{cost of GHG}) \qquad (iii)$$

Thus, legumes are environment-friendly crops and are different from other food plants because of the property of synthesizing atmospheric nitrogen into plant nutrients. The economic valuation has been done by taking into account the positive externality of legume crops by biological nitrogen fixation and the negative externality of GHG emissions.

Results and Discussion

The state has well developed surface and groundwater irrigation infrastructure. The surface irrigation distribution network comprises 1, 45,000 kilometres of canals including branch canals and minor distributaries and one lakh kilometres of field channel or water courses. Even then canal irrigation system irrigated about one-third of the net irrigated area in the state. The share of canal irrigation has declined sharply from 44.87per cent in the triennium ending (TE) 1973 to 38.83 per cent in the TE 1993 and further to 27.29 per cent in the TE 2013 (Table 1). On the other hand, the groundwater irrigation i.e. tube well irrigation particularly in the central and northern regions of Punjab has been on the increase. During 1970's irrigation done by using groundwater accounted for 55.13 per cent which has jumped to 72.71 per cent in TE 2013

Table 1: Irrigation pattern in Punjab

Particular	TE 1973	TE 1983	TE 1993	TE 2003	TE 2011	TE 2013
Net irrigated area (000ha)	2928	3447	3872	4035	4068	4085
Irrigated (% to Net Area Sown)	71.67	82.00	92.00	95.00	97.73	98.67
Irrigation Coverage						
1. Surface Water (%)	44.87	40.76	38.33	26.36	27.39	27.29
2. Ground Water (%)	55.13	59.24	61.67	73.64	72.61	72.71
Total no. of Pumps(Lakh)	2.62	6.11	8.11	11.05	13.43	13.80
1. Electric Motors (%)	38.42	49.81	76.49	74.03	80.62	84.28
2. Diesel Pumps (%)	61.58	50.19	23.51	25.97	19.38	15.70

*Statistical Abstract of Punjab, Various Issues

The important reason behind such increase in the use of groundwater resource is phenomenal increase in the growth of groundwater abstraction structures (tubewells) due to their technical feasibility (groundwater is sweet) and economic viability (electricity to pump out water for irrigation is free) backed by huge investment in generation and distribution of power to farm sector and good quality seeds and use of chemical fertilizers. There has been sharp increase in the total number of tube wells from 2.62 lakh in TE 1973 to8.11 lakh in the TE 1993 and then to 13.80 lakh in the TE 2013 in the state. The share of electric operated tube wells in the total number of tube wells increased from 38.42 percent in the TE 1973 to 84.28 per cent in the TE 2013 while the share of diesel operated tube wells during the same period has declined from 61.58 per cent to 15.70 per cent. Subsidized power to agriculture has led to installation of more and more electric-tube wells and consequent greater withdrawal of groundwater than ever before.

The status of water resources in Punjab depicted in Table 2 reveals that annual groundwater draft the state during the period of study was of 34.88 billion cubic meters. Availability of annual replenishable groundwater in the state was of 22.53 BCM of which water available from rainfall and other resources was 7.15 BCM and 15.38 BCM respectively thus, net annual groundwater availability was of 20.32 BCM. The results brought out that the net groundwater availability for future irrigation use will be of -14.56 BCM in the Punjab State.

Table 2: Status of water resources in Punjab State as on 31st March, 2011

Particulars	Value (BCM)
Annual replenishable groundwater resources	22.53
1. From Rainfall	7.15
2. From other sources	15.38
Natural discharge during non-monsoon period	2.21
Net annual groundwater availability	20.32
Annual groundwater draft	34.88
Net Ground water availability for future irrigation use	-14.56

Source: Dynamic ground water resources of India. 2011

Table 3: Categorization of blocks based on groundwater development in 2010-11

Category	No. of blocks	Share in total assessment units
Safe	22	15.94
Semi-critical	2	1.45
Critical	4	2.90
Over-exploited	110	79.71
Total assessment units	138	100.00

Source: Dynamic ground water resources of India. 2011

Widespread rural electrification coupled with a flat free electricity subsidy that has led to a dramatic increase in the number of tube wells and groundwater based irrigation now far surpasses surface water use. In the absence of any systematic policy to regulate the demand for water, the unconstrained mining of this resource has resulted in over exploitation of groundwater. Out of the total 138 blocks in the State, 110 blocks were found over exploited, 4 blocks as critical, 2 blocks found semi-critical and only 22 blocks were in the safe category. The share of over exploited blocks in the total blocks of the State was 79.71 per cent (Table 3).

The largest component of ground water use is the water extracted for irrigation. Of all the sources (canals and tubewells) of irrigation, ground water constitutes the largest share. Over the years, there has been a continuous increase in ground water utilization for irrigation while the use of surface water has declined. The practice of providing power subsidies for agriculture has played a major role in decline of water levels in the state. The extent of groundwater use varies across different crops depending upon the pumping hours and average yield (cubic meter/hour) of the pumps. The use of irrigation hours for groundwater extraction in various crops in Punjab is presented in Table 4.

It was found that Punjab farmers run tube wells for 252.46 hours to cultivate one hectare of paddy followed by 179.07 hours for sugarcane, 52.92 hours for wheat, 34.92 hours for maize and 33.25 hours for cotton. The pumpwise decomposition further revealed that about 50 per cent of the groundwater irrigation is given using submersible pumps except for cotton and sugarcane. The dominance of submersible pumps for major crops indicates a deeper water table in large part of the state. For cotton cultivation, submersible pumps are not used primarily because the crop is grown in water logging and salinity affected south-western part of the state. Due to salinity problems farmers prefer canal irrigation and use groundwater as a supplementary irrigation.

Table 4: Machine hours used for groundwater extraction in various crops in Punjab, TE 2010-11

Crops	Ground water irrigation hours (Hours/ha)			
	Diesel pump	Electric centrifugal	Electric submersible	Total
Wheat	3.94(7.45)	19.32(36.51)	29.66(56.04)	52.92(100.00)
Paddy	16.90(6.69)	110.01(43.58)	125.55(49.73)	252.46(100.00)
Basmati	9.50(3.58)	77.08(29.05)	178.80(67.37)	265.39(100.00)
Cotton	23.58(70.93)	6.84(20.56)	2.83(8.50)	33.25(100.00)
Maize	5.86(16.79)	12.11(34.69)	16.94(48.52)	34.92(100.00)
Sugarcane	28.36(15.84)	64.45(35.99)	86.27(48.18)	179.07(100.00)
Sugarcane ratton	19.42(8.62)	151.54(67.22)	54.46(24.16)	225.43(100.00)
Potato	16.03(13.15)	39.88(32.71)	66.00(54.14)	121.90(100.00)
Rapeseed	2.68(7.54)	21.15(59.59)	11.66(32.87)	35.49(100.00)
Fodder	6.82(6.69)	33.23(32.60)	61.89(60.71)	101.94(100.00)
Vegetables	0.00(0.00)	25.70(20.51)	99.58(79.49)	125.28(100.00)
Barley	2.04(3.54)	13.10(22.72)	42.51(73.74)	57.65(100.00)
Pea	0.15(0.30)	9.36(18.83)	40.20(80.87)	49.71(100.00)
Gram	22.50(56.25)	0.00(0.00)	17.50(43.75)	40.00(100.00)
Moong	19.83(55.05)	0.00(0.00)	16.19(44.95)	36.02(100.00)
Urad	6.66(21.32)	7.08(22.66)	17.50(56.02)	31.24(100.00)

Groundnut	23.33(29.32)	56.25(70.68)	0.00(0.00)	79.58(100.00)
Sunflower	35.04(35.36)	38.40(38.75)	25.66(25.89)	99.10(100.00)
Mesta	4.27(2.60)	159.70(97.40)	0.00(0.00)	163.97(100.00)
Arhar	10.95(9.24)	65.06(54.92)	42.46(35.84)	118.47(100.00)
Oilseeds	0.00(0.00)	0.00(0.00)	111.29(100.00)	111.29(100.00)

*Figures in parentheses indicate percentages to total groundwater irrigation hours.

The perusal of Table 5 reveals that among major crops, paddy was found to be the most water guzzling crop with the groundwater use of 11097.51 cum/ha during 2010-11. The groundwater use for cultivation of other crops was 9.29 (for maize) 40.34 (for cotton) and 83.47 (for sugarcane) per cent of the groundwater use in paddy depending upon the crop duration and water requirements. On an average, production of one kilogram of paddy in Punjab required 1702.77 litres groundwater and the estimated groundwater foot prints for other crops (except cotton) were much less than for paddy. Due to substantially high groundwater use, groundwater productivity (Rs/cum) of paddy was also much less than other crops. Thus paddy a dominant crop in the existing cropping pattern is ecologically not suitable for Punjab and thus resulting in rapid decline of water table in the state. It was also found that in terms of per unit production, basmati variety consumed 2984.770 litres/kg volume of groundwater than the paddy-non basmati (1702.71 litres/kg) due to substantially lower yield in the year 2010-11. Inspite of lower yield, large price differential made basmati variety more remunerative than thepaddy non-basmati. Therefore, it is imperative to say that replacement of paddy non-basmati with basmati variety, may improve the farmers' income but with reducing the pressure on depleting groundwater resources in the state. Thus paddy (common) was found to be the most water intensive crop with groundwater use of 11097.51 cum/ha followed by paddy basmati (11031.71 cum/ha). Sugarcane (ratoon) consumed 9288.26 cum/ha groundwater. Wheat consumed lesser water (3009.42 cum/ha) compared to paddy but higher than rapeseed (1467.38) and maize (1021.29 cum/ha). The widespread paddy cultivation in the state is found to be the main cause of large scale depletion of groundwater. Thus, cropping pattern is needed to be diversified to curb the depletion of groundwater in the state.

Table 5: Groundwater use and productivity in different crops in Punjab, TE 2010-11

Crops	Groundwater draft (Cum/ha)	Crop yield (Kg/ha)	Groundwater footprints (Lit/kg)	Gross returns (Rs/ha)	Groundwater productivity (Rs/cum)
Wheat	3009.42	4263.67	705.82	54167.63	18
Paddy common	11097.51	6517.33	1702.77	69000.55	6.22
Basmati	11031.71	3696.00	2984.77	79485.44	7.21
Cotton	4477.43	2137.00	2095.19	72267.03	16.14
Maize	1031.29	3647.67	282.726	34678.48	33.63
Sugarcane	9263.47	72044	128.581	152480.07	16.46
Sugarcane(ratton)	9288.26	74131.00	125.29	154101.16	16.59
Potato	3974.10	25164,00	157.92	71389.05	17.96
Rapeseed	1467.38	3837.67	382.36	31388.42	21.39
Fodder	5196.98	63294.67	82.10	37836.70	7.28
Vegetables	3222.64	11525.67	279.60	74532.16	23.13
Barley	2321.18	3745.00	619.81	40968.83	17.65
Groundnut	1609.23	692.00	2325.48	24375.00	15.15
Gram	2134.97	900.00	2372.19	34200.00	16.02
Moong	1322.41	736.00	1796.75	23344.90	17.65
Pea	1125.00	4945.00	227.50	71483.81	63.54
Urad	1293.60	441.00	2933.33	14511.66	11.22
Sunflower	2655.97	1786.00	1487.11	35042.01	13.19
Mesta	7426.13	5422.00	1369.63	47787.49	6.44
Arhar	4789.91	11300.00	423.89	37685.33	7.87
Oilseeds	2963.56	730.00	4059.67	37125.00	12.53

Optimal Crop Plans

The dominance of rice-wheat crop rotation has led to over exploitation of ground water resulting in rapid decline of water table in the entire state.

The existing groundwater draft in the state for irrigation is 34.88 BCM and annual groundwater draft 14.56 BCM (72%) is found higher than the sustainable limit of 20.32 BCM.Groundwater constraints have been used in LP model**.** Optimum crop plan for Punjab state under different scenarios have been developed as follows:

1. Existing use of water by not using the water constraint
2. Restricting groundwater use to 90 per cent of the existing level.
3. Restricting water use to 80 per cent of the existing level.

Under the scenario of existing water use

Table 6: Optimum crop model for existing water use for Punjab state (000'ha)

Crop	Current area	Optimum area at		
		Market price	Eco price	NRV price
Wheat	3505.00	3456.62	3456.62	3456.62
Paddy	2031.00	1975.51	1938.63	1938.63
Basmati	863.00	777.18	814.06	814.06
Cotton	405.00	585.83	585.83	585.83
Maize	125.00	154.34	154.34	154.34
Rapeseed	31.00	37.00	37.00	37.00
Potato	88.27	70.99	70.99	70.99
Sugarcane	94.00	150.00	150.00	150.00
K_Fodder	527.09	455.99	455.99	455.99
Barley	10.00	15.00	15.00	15.00
K_Vegetables	30.19	29.01	29.01	29.01
Arhar	2.60	3.36	3.36	3.36
Groundnut	1.40	3.00	3.00	3.00
Moong	3.70	2.78	2.78	2.78
Sesamum	4.80	3.60	3.60	3.60
Gram	1.80	2.09	2.09	2.09
Sunflower	8.50	9.42	9.42	9.42
R_Fodder	351.65	306.78	306.78	306.78
R_Vegetables	70.43	83.27	83.27	83.27
GCA	8154.43	8121.73	8121.73	8121.73
Profit (optimum plans at existing water use)		28821.15	21616.67	21262.56
Water(GW+Surface) Use (BCM)	49.81	48.89	48.90	48.90
Profit at existing cropping pattern		28137.21	20966.76	20688.17
Increase/Decrease in profit (%)		2.43	3.10	2.78

The optimum crop model suggests decrease in area at market prices under wheat (by 1.38%), paddy (2.73%), basmati (9.94%), potato (19.57%), kharif fodder (13.49%). The decrease in area under other crops such as kharif vegetables, moong, sesamum, rabi fodder by 3.09 per cent, 24.86 per cent, 25.00 per cent, 12.75 per cent, respectively (Table 6). There needs to be increase in area under cotton (44.65%), maize 23.47%), rapeseed mustard (19.35%), sugarcane (59.71%), sunflower (10.82%) and rabi Vegetables (18.23%). This plan suggests decrease in area under paddy by 2.73 per cent each at economic and NRV prices respectively and increase in area under basmati by 9.94 per cent each at economic and NRV prices. With such changes in area under different crops, gross cropped area would decrease from 8154.43 thousand hectares to 8121.73 thousand hectares at all the prices i.e. at market, economic and NRV prices respectively and profit would increase by 2.43 per cent, 3.10 per cent and 2.78 per cent respectively at all the respective prices and water use according to this plan would be less.

Irrigation water restricted to 90 per cent of existing use

With this restriction, at market price, the optimum plan suggested decrease in area under wheat, paddy, basmati, sesamum and fodder ranging between 1.38 per cent to 25per cent (Table 7). This plan advocate increase in area under cotton (37%), maize (188%), rapeseed and mustard (19%), sugarcane (56%), barley (50%), kharif vegetables (21%), arhar (70%), sunflower (5.41%) and rabi vegetables (18.23%). At economic and NRV prices, the optimum plan suggested decrease in area under wheat by 1.52 per cent, under basmati by 21.63 per cent and moong by 24.86 per cent each respectively.

The changes in area under other crops found same at economic and NRV prices as were at market prices. With such changes in area, the gross cropped area decreased from the current area of 8154.43 thousand hectares to 7931 thousand hectares, 7927.67 thousand hectares and 7929.50 thousand hectares at market, economic and NRV prices. Thus with 10 per cent saving in water, the profit would decrease by 3.52 per cent, 3.53 per cent and 3.60 per cent respectively at market, economic and NRV prices.

Table 7: Optimum crop model for water restricted to 44.85 BCM (90 % of current water use) for Punjab state (000'ha)

Crop	Current area	Optimum area at		
		Market price	Eco price	NRV
Wheat	3505.00	3481.21	3476.21	3476.21
Paddy	2031.00	1669.91	1607.57	1606.53
Basmati	863.00	724.46	786.96	786.96
Cotton	405.00	557.37	557.37	557.02
Maize	125.00	360.29	360.29	360.29
Rapeseed	31.00	37.00	37.00	37.00
Potato	88.27	70.99	70.99	70.99
Sugarcane	94.00	147.46	147.46	147.46

K_Fodder	527.09	416.99	416.99	416.99
Barley	10.00	15.00	20.00	20.00
K_Vegetables	30.19	36.68	36.69	36.69
Arhar	2.60	4.44	1.95	4.44
Groundnut	1.40	3.00	3.00	3.00
Moong	3.70	4.19	2.78	2.78
Sesamum	4.80	3.70	3.70	3.70
Gram	1.80	1.35	1.35	2.09
Sunflower	8.50	8.96	8.96	8.96
R_Fodder	351.65	282.18	282.18	282.18
R_Vegetables	70.43	83.27	83.27	83.27
GCA	8154.43	7908.44	7904.70	7906.54
Profit (optimum plans with 90 % of current water use)		27147.72	20227.16	19943.34
Water(GW+Surface) Use (BCM)	49.81	44.95	44.85	44.85
Profit at existing cropping pattern		28137.21	20966.76	20688.17
Increase/Decrease in profit (%)		-3.52	-3.53	-3.60

Irrigation water restricted to 80 per cent of existing use

This plan suggests to decrease the area under wheat crop by 11 per cent at market prices, 12.22 per cent at economic prices and 12.21 per cent at NRV prices (Table 8). This plan suggested decrease in area under basmati, cotton, kharif fodder, moong, sesamum, gram and sunflower ranging between 13. 55 percent to 27 per cent. But at NRV prices the optimum plan suggested an increase in area under gram by 65 per cent. The area under rapeseed & mustard doubled from 31 th to 62 th under each price scenario, whereas area under maize crop increased more than three time (from 125 th to 397 th) at market price, economic price and NRV price condition respectively. The gross cropped area would decrease from 8154.43 th to 7142.74, 7085.03 and 7085.58 th respectively at market, economic and NRV prices. With 20 per cent savings in water use, the profit would decrease by 14.38 per cent, 15.12 per cent and 15.11 per cent respectively at all the three prices i.e. at market, economic and NRV prices.

Table 8: Optimum crop model for water restricted to 39.84 BCM (80 % of current water use) for Punjab state (000'ha)

Crop	Current area	Optimum area at		
		Market price	Eco price	NRV price
Wheat	3505.00	3195.30	3156.29	3155.22
Paddy	2031.00	1523.25	1523.25	1523.25
Basmati	863.00	631.15	631.15	631.15
Maize	125.00	396.83	355.61	355.61
Cotton	405.00	303.75	303.75	303.75
Rapeseed	31.00	62.00	62.00	62.00
Potato	88.27	66.20	66.20	66.20
Sugarcane	94.00	127.16	147.46	147.46
K_Fodder	527.09	416.99	416.99	416.99
Barley	10.00	12.50	12.50	12.50
K_Vegetables	30.19	36.68	36.69	36.69
Arhar	2.60	1.95	1.95	1.95
Groundnut	1.40	3.00	3.00	3.00
Moong	3.70	2.78	2.78	2.78
Sesamum	4.80	3.60	3.60	3.60
Gram	1.80	1.35	1.35	2.97
Sunflower	8.50	6.38	6.38	6.38
R_Fodder	351.65	282.18	282.18	282.18
R_Vegetables	70.43	83.27	83.27	83.27
GCA	8154.43	7156.30	7096.38	7096.92
Profit (optimum plan with 80 % of current water use)		24090.63	17795.82	17562.80
Water(GW+Surface) Use (BCM)	49.81	39.84	39.84	39.84
Profit at existing cropping pattern		28137.21	20966.76	20688.23
Increase/Decrease in profit (%)		-14.38	-15.12	-15.11

The gains due to optimum crop model over existing scenario of Punjab have been presented in table 9. Under the condition of existing water use there will be decrease in gross cropped area by 0.40 per cent each at market prices, economic prices and NRV prices (Table 9). The increase in farmers' revenue was estimated to be of Rs. 684 crores at market prices while these turned out to be negative at economic prices (Rs. -6521 crores) and NRV prices (Rs. -6875 crores). The gain to the society was found nil at market prices, while at economic and NRV prices these were estimated at Rs. 7170 crores and Rs. 6892 crores respectively. The net gain was estimated to be Rs. 680 crores, Rs. 650 crores and Rs. 17 crores at market prices, economic prices and NRV prices respectively.

Table 9: Gains due to optimum crop model over existing scenario of Punjab state

Optimum scenario (1)	Change in GCA (%) (2)	Existing revenue (Crores) (3)	Optimal net returns (Crores) (4)	Change in farmer revenue (Crores) (optimal - existing ^{MP}) (5)	Gain to society (Crores) (6)	Net gain (Crores) (7)=(5)+(6)
Existing water use						
MP	-0.40	28137	28821	684	0	684
EP	-0.40	20967	21617	-6521	7170	650
NRV	-0.40	20688	21263	-6875	6892	17
Restricted water use by 90 per cent						
MP	-3.11	28137	27148	-989	0	-989
EP	-3.06	20967	20227	-7910	7170	-740
NRV	-3.04	20688	19943	-8194	6892	-1302
Restricted water use by 80 per cent						
MP	-13.95	28137	24091	-4047	0	-4047
EP	-12.98	20967	17796	-10341	7170	-3171
NRV	-12.97	20688	17563	-10574	6892	-3682

Under the condition of restricted water use by 90 per cent there will be decrease in gross cropped area by 3.11 per cent, 3.06 per cent and 3.04 per cent at market prices, economic prices and NRV prices respectively. The farmers' revenue was estimated to be Decreased by Rs. 989 crores at market prices while at economic prices and NRV prices the farmers income was estimated to decline by Rs. 7910 crores and Rs. 8194 crores respectively. The net loss was estimated of Rs. 989 crores, Rs. 740 crores and Rs. 1302 crores at market prices, economic prices and NRV prices respectively.

Under the condition of restricted water use by 80 per cent there will be decrease in gross cropped area by 13.95 per cent, 12.98 per cent and 12.97 per cent at market prices, economic prices and NRV prices respectively. The farmers' revenue was estimated to decrease by Rs. 4047 crores at market prices while at economic prices and NRV prices, there will be decline of Rs. 10341 crores and Rs. 10574 crores respectively in Farmers revenue. The net loss was estimated to be of Rs. 4047 crores, Rs. 3171 crores and Rs. 3682 crores at market prices, economic prices and NRV prices respectively.

Conclusions

Ground water depletion is a major issue in Punjab agriculture due to its over exploitation. Paddy cultivation is considered to be the main reason for this because its cultivation requires high amount of water as compared to its competing crops. The falling water table in Punjab can be arrested by delaying the rice transplanting date from June 10 to June 30 will decrease the falling water table area. The time of rice transplanting to June 30 without affecting the sowing time of wheat and its yield will need to develop high yielding and short duration cultivars of rice. The delay in rice transplanting to June 30 will not only help in arresting the fall of water table but will also allow for an additional crop of summer moong after wheat harvest in areas of rising water tables. Some areas under rice should be shifted to other crops such as cotton, maize, sorghum for fodder, etc. As sowing of these crops is done much earlier than June 30. The efficiency of irrigation water can also be increased by using water saving technologies such as: Optimum irrigation scheduling, Laser land leveller and Tensiometer which helps in assessing the exact time and amount of irrigation water on the basis of available water in the soil can reduce the irrigation water requirements.

References

1. Aeschbach-Hertig W, Gleeson T. Regional Strategies for the Accelerating Global Problem of Groundwater Depletion, National Geographic Science. 2012; 5:853-861.
2. Anonymous Manual on Cost of Cultivation Surveys. DES (Directorate of Economics and Statistics), Department of Agriculture, Government of India, New Delhi, 2008.
3. Anonymous. Agricultural Statistics at a Glance. Ministry of Agriculture and Farmers' Welfare, Government of India, New Delhi, 2014a.
4. CGWB (Central Groundwater Board). Dynamic Groundwater Resources of India. Ministry of Water Resources, River Development and Ganga Rejuvenation, Government of India, Faridabad, 2014b.
5. GoPb (Government of Punjab) Punjab State Electricity Regulatory Commission. Available at: http://www.pserc.nic.in
6. Government of India (various issues) Annual Report of Ministry of Chemicals and Fertilizers, Department of Fertilizers, New Delhi.
7. Haddeland I, Heinke J, Biemans H, Eisner S, Florke M, Hanasaki N *et al*. Global Water Resources Affected by Human Interventions and Climate Change. Proceedings of the National Academy of Sciences. 2014; 111:3251-3256.
8. IARI (Indian Agricultural Research Institute) GHG Emission from Indian Agriculture: Trends, Mitigation and Policy Needs. Centre for Environment Science andClimate Resilient Agriculture, 2014, 16.
9. IIPR (Indian Institute of Pulses Research) Pulses in New Perspective. In: Proceedings of the National Symposium on Crop Diversification and Natural Resource Management. Kanpur, 2003, 20-22.
10. Jain AK. "Water Management Strategies in Punjab", India in 'Perspectives on Water' Powell and Mitra, 2012.
11. Kaur B, Vatta K, Sidhu RS Optimising Irrigation Water use in Punjab Agriculture Role of Crop Diversification and Technology. Indian Journal of Agricultural Economics. 2015; 70(3):305-318.

12. Kaur S, Vatta K. Groundwater Depletion in Central Punjab: Pattern, access and depletion, Current Science. 2015; 108(4):485:90.
13. Postel SL. Entering an Era of Water Scarcity: The Challenges Ahead, Ecological Application. 2000; 10(4):941-48.
14. Shah T. Climate Change and Groundwater: India's Opportunities for Mitigation and Adaptation, Environ. Research. Letters. 2010; 4:035005.
15. Srivastava SK, Srivastava RC, Sethi RR, Kumar A, Nayak AK. Accelerating Groundwater and Energy Use for Agricultural Growth in Odisha: Technological and Policy Issues. Agricultural Economics Research Review. 2014; 27(2):259-70.
16. Vorosmarty JC, Green P, Salisbury J, Lammers RB. Global Water Resources: Vulnerability from Climate Change and Population Growth. Science. 2000; 289:284-88.
17. World Bank India - Water Resources Management Sector Review: Groundwater Regulation and Management Report (English). World Development Sources, WDS 1998-3. Washington, DC: World Bank, 1998.