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Sustainable Irrigation Water Use in Punjab Agriculture: An Economic Analysis

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Abstract

The current study developed optimal crop plans by restricting irrigation water use and incorporating technologies like happy seeder, direct-seeded rice, and short-duration varieties. The technique of linear programming has been used to develop optimum plans using data collected under the "Comprehensive scheme for studying the cost of cultivation of principal crops in Punjab" pertaining to the year 2018-19. The optimal crop plans developed with 10 per cent savings in irrigation water recommend decreasing the area under paddy and potato crops while the area under maize, basmati, sugarcane, cotton, moong, barley, sunflower, and peas needs to be increased. Adopting the optimal plans with these technologies will help crop diversification, and increase returns. The optimal plans will help increase use of human labour while reducing chemical fertilizers use. Further, the money saved by the government from electricity subsidy provided to run tube wells can be utilized to develop agricultural infrastructure and offering competitive prices for less irrigation water-requiring crops.

Keywords: Sustainable, Irrigation water, Optimal plan, Agriculture, Technology, Returns.

JEL Classification: C53, Q02, Q11, Q12

Introduction

Water, soil, plants, renewable energy, climate, vegetation, environment, and so on are the most essential affective aspects of a country's agricultural output sector or communal wealth (Kumawat *et al* 2020). These resources are constantly depleting due to overexploitation. The ability to live and expand without diminishing the natural resources for the future is referred to as sustainability. Sustainable agriculture focuses on long-term production with the least environmental impact (Cunningham 2020). Development must ensure increase in agricultural production along with natural resource conservation. So, food security is not just about quantity but also about continuity. Water and soil are the two most important natural resources on which life depends (Wrachien 2002). So, this should be preserved, used, and managed in a sensible, equitable, sustainable, and economically reasonable manner. India is the major consumer of groundwater, consuming over twenty-five per cent of the world's fresh water and using 88 per cent of it for irrigation. Much of its agricultural production is dependent on excessive water consumption, and production areas are likely to face long-term water shortages. Currently, approximately 60 per cent of the country's underground aquifers are under severe stress (World Bank, 2008, 2010 and 2012).

The Punjab state of India has made incredible development in agriculture by becoming a major consumer of groundwater, due to effective agricultural policies. The majority of its agricultural production is dependent on a great deal of water, and production areas are likely to face long-term water shortages. Many studies show that Punjab agricultural is under threat due to unsustainability (Kaur *et al* 2010, Kaur *et al* 2015, Grover *et al* 2017 and Chand *et al* 2022). Therefore, the key objective of this study is to develop alternative crop plans under various technologies to conserve irrigation water by diversifying the agriculture along with increasing income of the farmers from crop production.

Data Sources and Methodology

The study is based on both primary as well as secondary data pertaining to Punjab state. The primary data of the scheme entitled, "Comprehensive Scheme for Studying the Cost of Cultivation of Principal Crops in Punjab" for the year of 2018-19 has been used to work out the input-output coefficients of different crops. In the course of conducting the "Comprehensive Scheme for Studying the Cost of Cultivation of Principal Crops in Punjab," a sample of 300 households was drawn from 30 tehsils in order to collect plot-specific data. Under this scheme farmers were chosen from the state's

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three agro-climatic zones using a three step stratified sampling approach, with the first stage being the tehsil, the second being a village or group of villages, and the third being the operational holdings within the cluster. Ten operational holdings, two from each of 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 randomly chosen from each cluster. Different technological, institutional, and policy interventions for sustainable improvement in farm incomes and resource use were identified. Input-output coefficients for new interventions and newly introduced crop activities were taken from available data.

Analytical tools

To understand the economic implications of different crop types, a budgetary analysis has been carried out. Various components in the cost of cultivation of crops under study were estimated in line with the methods provided in the manual of cost of cultivation like farm-produced and purchased, seed, chemical fertilizers and manures, plant protection chemicals, human labour, owned/hired machinery charges, and interest on working capital. Based on the cost concept used the overall costs included the farmers' paid-out expenses in cash and kind for various items of cost of the cultivation (Rs per ha) have been taken in the present study. Variable cost component compound of i) value of the seed, ii) value of fertilizer and manure, iii) value of plant protection chemicals, iv) value of human labour, v) value of machine labour (owned + hired), vi) value of irrigation charges, and the returns over variable costs have been calculated by subtracting variable cost from gross returns (Value of main product + Value of by-products).

In allocating areas for different crops and selecting combinations of enterprises, a mathematical technique called linear programming is often used to assist in decision-making. In order to compare various uses of limited resources based on changes in objectives and limitations, this tool is an easy and useful one. The impact of various options can also be simulated in this program. Various crop enterprise strategies have been established for this study with the use of a quasi-dynamic LP model to maximize the returns while taking into account constraints on area sown, human labour potential, irrigation water use, chemical fertilizers used, and working capital.

Mathematical specifications of the model

In order to mathematically express the model explanation for optimization, equations 1-7, followed by explanations for each, were used.

Objective function:

$$\text{Max } Z = \sum_{c=1}^{n} (Y_c P_c - C_c) A_c \qquad (1)$$

Where:

Z = Returns over variable costs

Y_c = Yield of main product & by-product (per hectare) of crop species 'c'

P_c = Price of crop output (main product & by-product) (Rs per unit of crop produce) of crop 'c'

C_c = Cost of cultivation (Rs per hectare) of crop 'c'

A_c = Area under crop species 'c'

c = Crop species

n = Number of crop species

Area constraint

$$\Sigma_t \Sigma_c A_{tc} \leq NS_t - OA_c \qquad (2)$$

Minimum area constraint

$$A_c \geq \min A_c \qquad (3)$$

Maximum area constraint

$$A_c \leq \text{Max } A_c \qquad (4)$$

$$A_c \geq 0$$

Where:

A_{tc} = Area occupied by crop species 'c' in the t^{th} month

NS_t = Net sown area

OAc = Area under orchard and other perennial crops

c = Crop species

t = Time (months of the year)

A_c = Area under crop species 'c'

Labour constraint

$$\Sigma_t \Sigma_c HL_{tc} \leq THL_t \qquad (5)$$

Other inputs (ground water, fertilizers, and working capitals) constraints

$$\Sigma_c X_c A_c \leq CUX \qquad (6)$$

$$A_c \geq 0 \qquad (7)$$

Where:

HL_{ti} = Monthly human labour (per hectare)

THL_t = Total human labour availability in the t^{th} month

X_c = Input use per crop (i.e., working capital, ground water, and fertilizers)

A_c = Area under crop

CUX = Availability of working capital, ground water, and fertilizers

Irrigation water use is widespread in almost the whole crop area of Punjab. In fact, three seasons of harvest are typical for crops in the state: (i) monsoon, also called *kharif* (starts from July to October), (ii) winter, also called *rabi* (November to March), and (iii) summer (March to June).

Paddy, cotton, maize, and other crops such as arhar, guar, moong, groundnut, and urad are the cultivated crops of this *kharif* season. The main crops in the *rabi* season are wheat, potato, and mustard. However, some of the traditionally cultivated crops that lost their own area are gram, sunflower, lentil, and barley. In summer, which is also called Zaid season, moong grows only at a short window of 50 to 70 days.

A total of 20 farm activities were included in this model. Crop and enterprise planning using LP primarily takes the supply-side behavior, more precisely, the area response based on returns and resource constraints, ignoring the demand aspects. This makes some of the areas allocated to certain crops appear to be underestimated or overestimated in these models. On the basis of experts' advice elicitation method and previous crop pattern area, minimum and maximum areas to remain under different crops have been determined. While the per unit requirement coefficients of human labour hours, working capital, and chemical fertilizer were estimated using data from the cost of cultivation, the per hectare requirement of irrigation water use for various crops was calculated using the approach suggested in earlier studies (Cooper *et al* 2011, Srivastava *et al* 2015, Pojara and Shahid 2016, Yadav *et al* 2017, Anonymous 2019, Anonymous 2021, and Chand *et al* 2022). Three distinct data sources have played a major role in the availability of resources. In terms of land, the total net sown area, excluding the area under perennial crops, were considered to be the net sown area, while the number of farmers and agricultural workers were used to estimate the total labour availability in the state. Taking into account that working capital and fertilizer usage in Punjab is already higher, the use of these sources under the current crop pattern forms the right-hand side of the constraint equations.

Results and Discussion

In this study, the linear programming (LP) framework has been solved using MS Excel Solver, a program intended to find optimal solutions to decision-making issues. The matrix data sheet was created to build optimal crop plans based on the accumulated data and methodology described above. To generate optimal crop plans by restricting the irrigation water use to 90% of its current level, many repetitions of purifying crop plans under various technologies have been performed (Table 1).

Optimal plan developed under existing resources use and technologies

The results of the optimal plan developed under existing resources use and technologies suggested that the area under paddy in the *kharif* season should be decreased to 16 lakh from 27.43 lakh hectares and shifted to maize, basmati, moong, cotton, and sugarcane. The area under *kharif* and *rabi* pulses remains the same as the previous existing area. The area under sunflowers, peas, and barley should be increased by decreasing the area under potato from 1.07 lakh to 0.60 lakh hectares. It will help to become self-sufficient for edible oils; however unforeseen rainstorms during harvest can occasionally cause problems. The cropping intensity (CI) under the existing optimized model will decrease to 192.09 per cent from 193.68 per cent.

Optimal plan with technology-I (Happy Seeder)

The optimized plan developed using technology of wheat sown with Happy Seeder. This plan suggests sowing 21 per cent of the current wheat area with Happy Seeder. The plan has suggested increasing the area under cash crops like cotton (increased from 2.51 lakh to 5.88 lakh hectares), and sugarcane as well as doubling the area under basmati paddy while decreasing the area under paddy by 39.7 per cent. This is in line with the state's draft agricultural policy, which calls for switching 1.2 million hectares from rice to less water-intensive crops like maize, cotton, sugarcane, pulses, oilseeds, fruits, and vegetables (Taneja *et al* 2018). In this plan also, the area under *kharif* and *rabi* pulses remains the same. The area under *rabi* oilseeds; sunflower increased by 104 per cent from the current area allocation, it will be a good step towards making the state self-sufficient in edible oils (Anonymous 2022). The area under peas and barley also increase by decreasing the area under potato.

Optimal plan with technology -II (Happy Seeder & Direct Seeded Rice)

The optimum plan developed by introducing activity, viz. wheat sown with happy seeder (HS) and direct seeding of rice (DSR) recommends that 7.41 lakh hectares of wheat should be cultivated using Happy Seeder technology for sowing of wheat crop. Like other plans, this plan also suggests decreasing the area under paddy while increasing the area under basmati and cotton during the *kharif* season. The government should make arrangements for the export of basmati. Further, this plan suggests that out of the total recommended area for paddy cultivation, around 5.9 per cent should be cultivated using DSR technology. The plan also advocates bringing more area under sunflower, which will be a good step towards crop diversification. The government may further encourage the farmers to bring more area under oilseed crops by providing a competitive price. By adopting this plan GCA will increase from 73.85 lakh hectares to 74.35 lakh hectares.

Optimal plan with technology-III (Happy Seeder & Short Duration Varieties)

The optimal plan developed with the technology being wheat sown with happy seeder and short-duration varieties for paddy recommends the same area under wheat with 7.41 lakh hectares (21%) sown using the technology of happy seeder. As per the optimum plan, the total area under paddy needs to be decreased from 27.43 lakh hectares to 19.80 lakh hectares, and further, out of these 12.5 lakh hectares,

Table 1. Existing area vis-a-vis area under optimum plans with 90 % irrigation water use in Punjab Agriculture (Thousand ha)

Crop Category	Crops	Current Area	Optimal plan under existing technology	Optimum plan under technology HS	Optimum plan under technologies HS and DSR	Optimum plan under technologies HS and SDVs	Optimum plan under all technologies
Rabi Cereals	Wheat	3530	3530	2789	2789	2789	2789
	Wheat (HS)			741	741	741	741
	Wheat Total	3530	3530	3530	3530	3530	3530
	Barley	6	26	13	44	6	15
Kharif Cereals	Paddy	2743	1600	1655	1550	730	680
	Paddy DSR				161*		64
	Paddy PR121					625	625
	Paddy PR126					625	625
	Paddy Total	2743	1600	1655	1711	1980	1994
	Maize	108	382	382	382	226	216
	Basmati	406	862	862	862	862	862
Kharif pulses	Arhar	3	3	3	3	3	3
	Guar	33	33	33	33	32	33
	Moong	24	40	40	40	24	24
	Urad	2	2	2	2	2	2
Rabi Pulses	Gram	2	2	2	2	2	2
	Lentil	1	1	1	1	1	1
Rabi Oilseeds	Mustard	32	32	32	32	32	32
	Sunflower	3	5	5	5	5	5
Kharif Oilseeds	Groundnut	2	2	2	2	2	2
Vegetables	Potato	107	60	60	60	60	60
	Peas	44	50	50	50	50	50
Cash Crops	Cotton-BT	252	588	588	588	588	588
	Sugarcane	89	108	121	89	95	89
Irrigation water use (BCM)		29.06	26.16	26.16	26.16	26.16	26.16
Gross cropped area (GCA)		7385	7324	7380	7435	7498	7508
Cropping Intensity (CI) (%)		193.68	192.09	193.54	195	196.65	196.93
Net returns over A2+FL		483.69	466.72	475.12	477.57	514.19	515.13

**DSR*

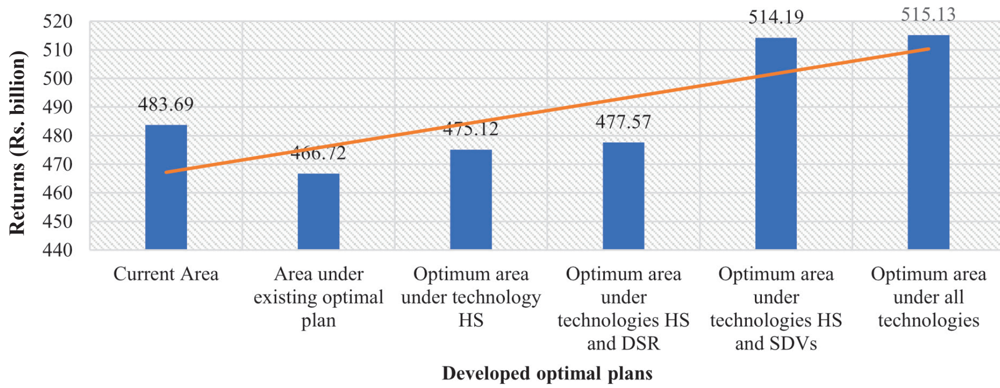

Figure 1. Changes with 90 % irrigation water use scenario and farmers' income under different optimal plans in Punjab.

should be under short duration varieties (PR 121 and PR 126) developed by the Punjab Agricultural University. The area under basmati paddy should be increased from 4.06 lakh hectares to 8.62 lakh hectares, while the area under sugarcane should be increased from 0.89 lacks to 0.95 lakh hectares. During the *rabi* season, this plan advocates reducing the area under potato while increasing the sunflower, and peas area. By adopting the recommendations of this plan, the returns can be increased by more than 6.3 per cent along with saving on electricity used for running electric tube wells for irrigation. The subsidy amount saved from electricity may be utilized by the government for developing infrastructure for agriculture. Besides saving irrigated water, the cropping intensity will increase to 196.65 per cent from 193.68 per cent by adopting this plan.

Optimal Plan with All Interventions

The optimal plan by introducing all the technologies (i.e. wheat sown with HS, paddy cultivation using DSR technology and SDVs) suggest 7.41 lakh hectares of wheat area to be cultivated using happy seeder technology in the *rabi* season. This plan recommends that the total area under paddy should be 19.94 lakh hectares in place of the current 27.43 lakh hectares. Further, out of these 19.94 lakh hectares 0.64 lakh hectares should be sown directly using DSR technology and for 12.5 lakh hectares short duration variety (PR 121 and PR 126) seed should be used. The optimum plan advocates increasing the area under maze, basmati, and cotton, which is released from paddy cultivation. Also, the area under potato should be decreased from 1.07 lakh hectares to 0.60 lakh hectares, and should increase the area of sunflowers from 0.26 lakh hectares to 0.51 lakh hectares. Achieve cropping intensity of 196.93 per cent and following the GCA to increase from 73.85 lakh hectares to 75.08 lakh hectares. This would result in increasing their returns over variable costs by 6.50 per cent in the state.

Effect on Resources Use and Income

The optimal crop plans developed with saving of irrigation water by 10 per cent (2.9 BCM), will help in restricting the downward movement of groundwater level and ultimately help in making agriculture sustainable. By adopting these plans the government can save a handsome amount of subsidy spent for providing free electricity to run the tube-wells. With the saved amount the farmers can be compensated either by providing subsidies on other inputs or by increasing the price of output of other competing crops. Changes in the returns over variable cost in various optimized plans under restricted irrigation water use at 90 per cent scenarios for Punjab have been shown in Figure 1. The returns can be increased ranging from 6.31 per cent to 6.50 per cent (Rs. 514.19 to 515.13 Billion) by adopting the optimal crop plans developed with incorporating various resource saving technologies like Happy Seeder for wheat, and short duration varieties for paddy cultivation and using these technologies in combination (HS, DSR, and SDVs).

Positive effects on the human labour and working capital use under various optimized plans for Punjab have been shown in Figure 2. By adopting the optimum crop plans developed with the restricted 90 per cent irrigation water use by introducing various technologies, human labour use will increase from 3.63 to 7.27 per cent. This will help in increasing the use of the underutilized resource of human labour. Also, changes in the working capital use under various optimized plans with 90 per cent restricted scenario. Various optimum plans require more working capital and the same can be met by availing loans from cooperation societies/banks from where it is readily available at the nominal interest rate.

Utilization of the chemical fertilizers under various optimized plans with 90 per cent restricted irrigation scenario for Punjab has been shown in Figure 3. It can be seen that the farmers can reduce the use of chemical fertilizers by adopting the optimum plans developed using various technologies which is good for Punjab agriculture where its use is higher than the recommended level. It will help in reducing the cost of cultivation. By adopting the optimum plans with the restricted 90 per cent irrigation water use, the farmers can

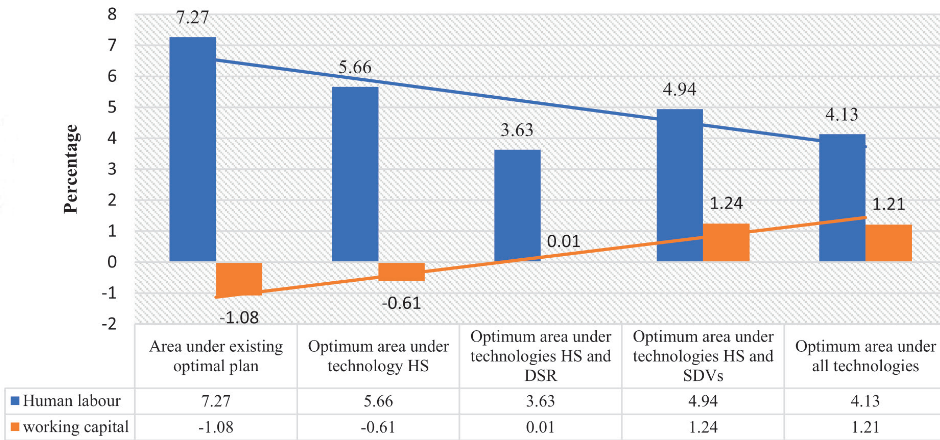

Figure 2. Changes with restricted 90 % irrigation, human labour and working capital use under different optimal plans in Punjab.

reduce the use of nitrogen fertilizers ranging from 2.69 to 4.35 per cent from their current use. Similarly, for phosphatic fertilizers, the reduction in usage will be 0.16 to 0.28 per cent, and for potassic fertilizers the reduction will be in the range of 20.45 to 30.16 per cent from its current use.

Conclusion and Policy Implications

The optimal crop plans developed by restricting the irrigation water use to 90% of its current level recommends decreasing the area under paddy and shifting to maize, basmati, moong, cotton, and sugarcane. During the *rabi* season, the plans suggest decreasing the area under potato and increasing the area under barley, sunflower and peas. By following the cropping pattern suggested in the optimum plans, the farmers can utilize higher human labour; which is mostly underutilized. The optimized plan developed using technology of wheat sown with Happy Seeder suggests sowing part of the current wheat area with Happy Seeder. This plan has suggested increasing the area under maize, moong, cotton, and sugarcane as well as doubling the area under basmati paddy while decreasing the area under paddy. Increasing the area under *rabi* oilseeds, sunflower from the current area will be a good step towards making the state self-sufficient in edible oils.

The optimum plan developed by introducing activities viz. wheat sown with Happy Seeder and direct seeding of rice recommends decreasing the area under paddy while increasing the area under maize, basmati, moong, and cotton during the *kharif* season. The government should make arrangements for the export of basmati. Further, this plan suggests that out of the total area of paddy, some area should be cultivated using DSR technology.

The plan also advocates bringing more area under sunflower, which will be a good step towards crop diversification. The government may further motivate the farmers to bring more area under oilseed crops by offering a competitive price. The optimum plan with the technology

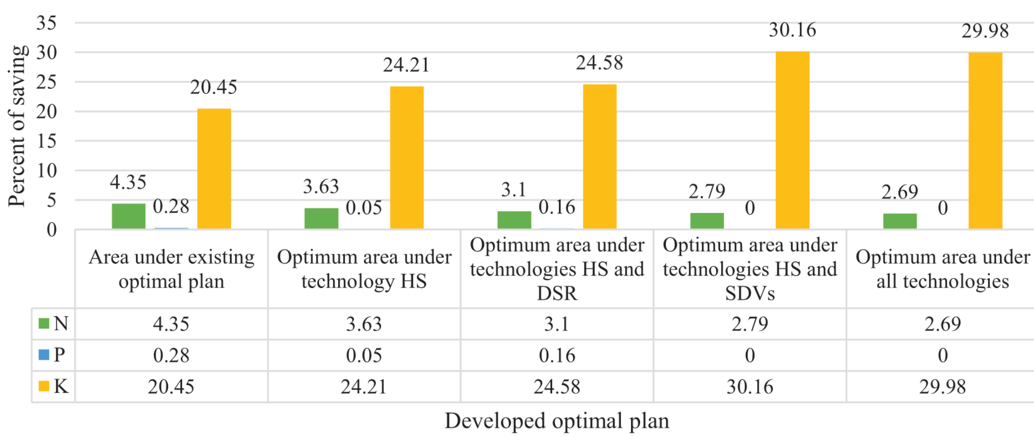

Figure 3. Changes with 90 % irrigation water use scenario and chemical fertilizer use under different optimal plans in Punjab.

of HS and short duration varieties (SDVs) recommends less area under paddy and further bringing area under (SDVs). By adopting the recommendations of this plan, the returns can be increased along with savings on electricity used for running electric tube wells for irrigation. Similarly, the adoption of the optimum plan developed using all the above-mentioned technologies (i.e., wheat sown with HS, paddy cultivation using DSR technology, and SDVs of paddy) recommends to allocate lesser area under paddy and more area under new technologies which will help in saving irrigation water use along with higher returns from farming. The subsidy amount saved from electricity may be utilized by the government for developing infrastructure for agriculture. By adopting these optimum plans, the farmers can utilize more human labour (which is underutilized), save irrigation water (which is over-utilized), and reduce fertilizers use where its use is quite higher than the recommended levels, ultimately saving the cost, and increase the farmers returns.

References

Anonymous 2022. *Edible oil imports in Jan 2nd highest; record shipments of cooking oils in Nov-Jan.* The Economic Times, Feb 15, 2023.

Chand P, Singh J M, Sachdeva J, Singh J, Agarwal P, Jain R, Rao S and Kaur B 2022. Irrigation water policies for sustainable groundwater management in irrigated northwestern plains of India. *Current Science* **123**: 1225-31. Doi: 10.18520/cs/v123/i10/1225-1231.

Cooper W W, Seiford L M and Zhu J 2011. *Data envelopment analysis: History, models, and interpretation.* University of Texas, USA, pp 37-40.

Cunningham M 2020. What is sustainable in agriculture?. https://study.com/academy/lesson.

GOP 2019. *Fostering prosperity for all*. Economic and Statistical Organization, Government of Punjab, Chandigarh, pp 125-26.

GOP 2021. *Statistical abstract of Punjab*. Economic Advisor to Government of Punjab, Chandigarh, pp 124-166.

Grover D K, Sing J M, Kaur A and Kumar S 2017. *State sagricultural profile – Punjab*. Economic Research Center, Punjab Agricultural University, Ludhiana, pp 29-44.

Kaur B, Sidhu R S and Vatta K 2010. Optimal crop plans for sustainable water use in Punjab, *Agricultural Economics Research Review* **23**: 273-84.

Kaur B, Vatta K and Sidhu R S 2015. Optimising irrigation water use in Punjab Agriculture: Role of crop diversification and technology. *Indian Journal of Agricultural Economics* **70**: 307-318.

Kumawat A, Yadav D, Samadharmam K, and Rashmi I 2020. *Soil and water conservation measures for agricultural sustainability*. Indian Council Agricultural Research, New Delhi, India, pp 1-24.

Pojara M K and Shahid A 2016. Crop diversification: Challenges of switching crops in Punjab. *Indian Journal of Economics Development* **12**: 579-82.

Srivastava S K, Chand R, Raju S S, Jain R, Kingsly I, Sachdeva J, Singh J, and Kaur A P 2015. Unsustainable groundwater use in Punjab agriculture: Insights from cost of cultivation survey. *Indian Journal of Agricultural Economics* **70**: 365-78.

Taneja G, Rawat S and Vatta K 2018. Towards unsustainable resource use in Punjab agriculture *Indian Journal of Ecology* **45**: 342-46.

World Bank 2008. *Agriculture for development*. World Development Report. The World Bank Washington D. C. USA, pp 150-386.

World Bank 2010. *World Development Indicator*. Washington, D.C. 20433, USA, pp.200-492.

World Bank 2012. *India groundwater: a valuable but diminishing resource.* PDF text web at https://www.worldbank.org/en/news/feature/2012/03/06/india-groundwater-critical-diminishing).

Wrachien D D 2002. *Land Use Planning: A Key to Sustainable Agriculture.* Institute of Hydraulics Agricultural State University of Milan, Italy, pp 1-11.

Yadav P, Srivastava S K and Agarwal P K 2017. Comparative study on cost of cultivation and economic returns from major crops in eastern region of Uttar Pradesh. *International Journal of Agricultural Environment and Biotechnology* **10**: 387-399. DOI: 10.5958/2230-732X.2017.00047.X.

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