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Climate adaptation strategies: optimizing farm-level water use and profitability in Punjab

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Abstract This study aims to develop optimal crop plans for farmers in Punjab who adopt climate-resilient technologies. In the macro perspective, the optimal crop plan envisages that 7.02 lakh hectares should be under paddy Punjab Rice Varieties (PR VAR) and 4.44 lakh hectares under paddy direct seeded rice. Raising the acreage of maize by 24% will save 3.42 billion cubic metre of water. Strengthening the linkages between research, extension, insurance, and institutional support would improve the capacity of farmers for adopting farm-level climate-smart practices and make the agriculture sector sustainable.

Keywords Farm-level adaptation, crop plan, water sustainability

JEL codes Q25, Q54, Q58

In the state of Punjab, the rice–wheat crop rotation is dominant; to facilitate it and make India self-sufficient in foodgrains, the area under major crops was raised by 87% over the past five decades. From 1960–61 to 2017–18, the area under paddy increased 13 times and the area under wheat 2.5 times (PAU 2018). The availability of groundwater and surface water was taken for granted, however, and unsustainable overuse and pollution over the past 50 years depleted it in many places and degraded aquifers (Kaur 2011; Burke et al. 1999; Sophocleous 2003). The erratic rainfall behaviour—deficit rainfall, long dry spells, and extreme weather events—reduced the groundwater recharge and balance further. The balance, 0.027 million hectare metre (m ha m) in 1997, fell to –1.063 m ha m in 2017. The net groundwater availability is –14.58 billion cubic metre (bcm).

The temperature increased at a high rate in recent decades, warming the global atmosphere by 1 ºC (IPCC 2014) and altering the rainfall patterns and hydrological cycle. The increasing frequency of extreme weather events, such as flooding and drought spells (Izaurralde et al. 2003), can be regarded as a change in the climate. Climate change affected the groundwater recharge process, reducing the supply of water and affecting the primary sector—and indirectly affecting the ecosystem and well-being. Climate change and variability endangers agricultural growth and the extent to which agricultural growth improves the quality of life, as the agricultural sector consumes 75% of the water worldwide (Falkenmark and Rockström 2008). A water management approach subservient to environmental and ethical considerations is needed, therefore.

Farmers need to mitigate the effects of climate change given their resource constraints, including the availability of water, to optimize the trade-off between net returns and water-saving. By choosing a sample of farmers from all the three zones of Punjab, this study attempts to develop optimal crop plans under the water availability regimes.

Materials and methods

We conducted this study in Punjab. We used a multi-stage random sampling technique to select the sample of farmers (200).

We selected two districts from the semi-hilly zone, Gurdaspur and SBS Nagar (Nawan Shehar), in the first stage. We selected Ludhiana district from the central zone and Faridkot district from the southwestern zone. In the second stage, we randomly selected one block from each district—Doraha from Ludhiana, Balachaur from SBS Nagar (Nawan Shehar), Dhariwal from Gurdaspur, and Faridkot block from Faridkot district. We then selected two villages from each block. At the third stage, we randomly selected from each village 25 farmers having experience in paddy and wheat cultivation.

We used primary data for the year 2016–17 to estimate the input and output coefficients for climate-resilient technologies. We used the profit-maximizing model of linear programming to obtain the normative plans that would maximize returns to fixed farm resources:

$$\text{Maximize } Z = \sum_{r=1}^{n} (NRr\ Ar)$$

$$\sum_{r} lrAr \leq \text{LA}$$

$$\sum_{r} krAr \leq KA$$

$$\sum_{r} Ars \leq As$$

$$\sum_{r} wrAr \leq WA$$

$Ar \geq \text{Amin}_r$

$Ar \leq \text{Amax}_r$

In the above equations,

n denotes number of activities;

Z denotes the net returns;

NR_r denotes net returns of crop r per hectare;

A_{rs} is the area under cultivation of crop r in hectares during season s;

A_s refers to per farm area under kharif and rabi seasons respectively;

CA_s is the cropped area during seasons;

s is kharif and rabi respectively;

l_r is the input coefficient of labour use in hours of crop r;

LA is labour availability per farm in hours;

k_r is the input coefficient of capital use of crop r in INR per hectare;

KA refers to per farm capital availability in INR;

w_r refers to actual water drawn per hectare for crop r in cubic metre;

WA refers to groundwater available;

Amin_r refers to minimum area limits of crops; and

Amax_r refers to maximum area limits of crops (Jain et al. 2015).

Programming model

Linear programming helps to optimize the net returns or income from crops or enterprises. A powerful tool, linear programming offers ways to simultaneously use scarce resources, which have alternative uses, under multiple sets of linear constraints and variables.

We formulated the model for both the kharif and rabi seasons—considering the constraints on the availability of land, labour, capital, and irrigation water—because these farm resources are scarce, and these have to be used judiciously to maximize net farm returns. To save water and maximize net returns, we developed optimal plans with and without irrigation constraints (Panda et al. 1983; Sankhayan and Cheema 1991; Jain et al. 2015; Jain et al. 2017; Jain et al. 2018).

Resource restrictions

Land area availability and utilization

We developed the land constraints for the crops in the sample separately for the kharif and rabi seasons. The farmers in the sample cultivated kharif crops (paddy, cotton, maize, summer moong, sugarcane, and kharif fodder) and also paddy crop, by allocating the area to PR varieties and the paddy area to the several resource conservation technologies.

In the rabi season, farmers allocated the area under wheat to improved varieties and ZTW, besides potato, sugarcane, and rabi fodder. The crop matrix considered these as separate activities; nine activities were conducted in the kharif season and six in the rabi season. The area cultivated in the existing cropping pattern is the land availability.

Human labour restriction

Punjab experiences a shortage of labour, especially during the transplanting and harvesting seasons, and high wage rates. We considered the availability of human labour as a constant. The primary survey recorded the use of human labour—family, attached servant, and hired labour—by crop.

We converted the family on-farm labour into adult person-hours to calculate the availability of labour. We analysed the number of family members (men and women) producing crops on the farm in the existing production pattern, and the percentage of time they spent producing crops, and converted the person-days of labour available per farm into person-hours of labour (1,443 person-hours).

Working capital

Credit is the most critical input for agriculture. The farmers in the sample met all the working expenses, or variable costs, for all the crops from their own funds or through short-term borrowing. We hypothesized that the amount spent on variable inputs in one season would be available for the subsequent crop, and we used this hypothesis to work out the capital used on the farm separately for the kharif and rabi seasons. About INR 77,492 was available in the kharif season and INR 66,115 in the rabi season.

Groundwater constraints

The actual groundwater drafted/used for each crop was calculated by multiplying irrigation hours used for that crop with the volume of water drawn out per hour by submersible motor. Thus, the volumetric use of water by each crop was worked out in this LP model and the kharif and rabi water constraints developed separately. The discharge rate of submersible motors having different energy (horsepower) at different water table depths were taken from Department of Soil and Water Engineering, PAU, Ludhiana.

For developing the coefficient of groundwater availability per farm, electricity is assumed to be available eight hours a day in the kharif season and four hours a day the rest of the year. The per-month supply of electricity converted into hours was further converted into the volume of groundwater drawn each month by considering the total number of submersible motors available on farms.

The procedural computations involved two steps. First, the number of submersible motors available was calculated. Then, the per-hour volume of groundwater drawn with the available motors was estimated. Secondly, the per-hour volume was multiplied with the hours of electricity supply. The total volume of groundwater so obtained was divided by the total number of farms to determine the volume of groundwater available (per farm) each month.

Some of the sample farmers had canal irrigation alongwith groundwater irrigation. This was duly taken care of and coefficients for both canal water available and use were hence calculated. Canal irrigation was received on area basis @ 75 min per hectare once a week from 15 th June till 15th September i.e. in kharif season ; accounting for 12 to 14 canal irrigations in paddy crop. The canal irrigated hours were converted into canal irrigated hectares and finally to groundwater hours(submersible motor hours) required to irrigate the same piece of land. Thus, the canal irrigated area (in hectare) was converted into submersible-motor-hour equivalents and, then, into the volume of water using the water discharge rate per hour of submersible motor use. Hence, the availability of irrigation water was the sum total of both groundwater plus canal water available.

Crop maxima and minima

The returns per hectare are quite high for enterprises like sugarcane (kharif) and potato (rabi), as are the productivity and price risks; restricting their maximum area would avoid a glut. The model necessitates the maximum and minimum areas to be demarcated; ignoring the demand aspect of minor crops will lead to over-estimating the area.

In this linear programming model, the returns for paddy DSR are much higher than for the conventional puddled method of sowing paddy, but DSR is recommended only in heavy soils, and it cannot be practised on all the area under paddy. Fodder crops feed livestock, and these must be grown on all farm holdings, and so we retained the area allocated to fodder crops in the existing cropping system.

Results and discussion

We discuss the results in four subsections: groundwater resources in Punjab; changes in temperature and rainfall in the past three decades; farm-level adaptation strategies needed to mitigate the effects of climate change; and the optimal plans for climate-resilient technologies.

Groundwater resources in Punjab

The green revolution improved crop productivity and food production but depleted natural resources, especially groundwater resources. The rice–wheat cropping system practised in Punjab, too, has depleted groundwater resources and widened the gap between the water supply available and the demand. The number of electricity- and diesel-operated tubewells grew from 7,000 in 1960–61 to 6 lakh in 1980–81 to 14.76 lakh in 2018–19. The state has made a huge jump in groundwater abstraction structures with a significant area under high-yielding varieties.

Kandi zone, which covers 19% of the state, has fewer irrigation facilities. The pumping of groundwater is feasible as water is fit for irrigation in the central zone, which covers 47% of the state. The southwestern zone covers 34% of the area of the state. The zone is known as the cotton belt of the state, but paddy has replaced a major part of the area under cotton, and farmers have been forced to install submersible pumps, extracting even more groundwater.

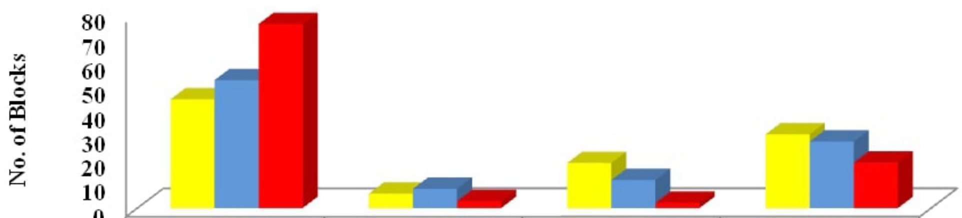
Electricity-operated tubewells can pump water from the depth of 150–200 foot; diesel-operated tubewells are suitable for lifting water only up to a depth of 30 foot (Sarkar and Das 2014). Groundwater irrigation has not only replaced surface water irrigation; it has also brought more area under assured irrigation, all through the spread of tube well technology. Three-fourths of the cropped area is now tube well irrigated (Vatta et al. 2013; Ghuman 2017), resulting in the over-exploitation of groundwater resources (Figure 1).

The percentage of dark, or overexploited, blocks—where the groundwater development exceeds 100%—swelled from 45% in 1984 to 76.09% in 2015; the percentage of semi-critical blocks, where groundwater development is 70–90%, decreased 9 times—from 18% in 1984 to 2% in 2015. This clearly reveals the significant shift from semi-critical blocks to over-exploited, or dark, blocks.

In Punjab, the per cent geographical area where water table is deeper than 10 m was 24.35% in 2000 and has increased to 79.04% in 2017 (Table 1). Presently, the large part of the state is in the over-exploited stage (Kaur B, 2008). As per central ground water board, deeper aquifers, having water table depth deeper than 10 metres have been marked as critical for water sustainability in the state (Table 1). In 2000, 75.65% of area in the state was in non-critical stage and thereafter about less than two decades from 2000 to 2017, 79.04% area came under critical stage and only 20.96% is in non-critical stage. Overall, more than 79% of Punjab is at the danger of water crisis.

Changes in temperature and rainfall

Table 2 depicts the annual change in temperature. In the rice-growing season (June to September), from 1986 to 2015, the mean temperature was 30.02 °C, the minimum 25.17°C, and the maximum 34.81°C. The mean temperature increased by 0.92°C during the



	Over-Exploited	Critical	Semi-Critical	Safe
1984	44.91	5.93	18.64	30.52
1997	52.89	7.97	11.59	27.55
2015	76.09	2.89	2.17	18.85

Figure 1 Per cent increase in over-exploitated and critical blocks in Punjab, 1984-2015

Table 1 Area under critical water-table depth in Punjab, 2000 to 2017 (% of geographical area)

Year	Percentage area <10 m	Percentage area >10 m	Percentage area >15 m	Percentage area >20 m	Percentage area >30 m
2000	75.65	24.35	-	-	-
2010	27.73	25.1	25.0	22.17	-
2017	20.96	11.83	32.36	18.1	16.75

Note Authors' own calculation

Table 2 Annual change in temperature and rainfall during rice- and wheat-growing period in Punjab, 1986 to 2015

Particulars	Maximum temperature (°C)	Minimum temperature (°C)	Mean temperature (°C)	Rainfall (mm)
Rice-growing period (June to September)				
Mean	34.81	25.17	30.02	511.32
Standard error	(0.010)	0.010	0.008	2.296
Change	0.32	1.59	0.92	-207.64
Annual change	0.017^{NS}	0.0529^{***}	0.0307^{***}	-6.9212^{***}
Wheat-growing period (November to March)				
Mean	24.59	11.20	17.58	101.88
Standard error	0.008	0.123	0.008	0.603
Change	0.27	1.25	0.86	-20.48
Annual change	0.0090^{NS}	0.04157^{***}	0.02856^{***}	-0.6826^{NS}

Note *** denote significance at 1per cent level, Figures in parentheses are standard errors, NS: Non-Significant
Source Kumar and Kaur (2019)

period. The wheat-growing period is cooler; the mean temperature is 17.58 °C, but the change in the maximum temperature (0.32°C) and in the minimum temperature (1.59°C) is higher in the rice-growing period, whereas the minimum temperature changed by 1.25°C in the wheat-growing period. The mean temperature in the rice-growing period increased by about 0.6°C than in the wheat-growing period, indicating that summers are becoming hotter.

Table 2 also depicts the annual change in rainfall. The region receives most of its annual rainfall in the rice-growing season, and it has decreased in all the agroclimatic zones of Punjab over the past 30 years—by 208 mm in the rice-growing season (6.92% per year) and 20 mm in the wheat-growing season (0.68%). By adversely affecting the rainfall and surface run-off, climate change can endanger the water resources and lead to acute scarcity.

Farm-level adaptation strategies

Adaptation to climate change and variability is imperative to sustain and improve production (Singh et al. 2015). Local-level adaptation measures may be modifications in operations, practices, and structures made to natural or human systems in response to actual or expected climatic stimuli, and these adaptation measures may range from short-term coping measures to long-term strategies (IPCC 2001; Tompkins and Adger 2003).

Farm-level adaptation strategies are agronomic practices, like the use of technologies to conserve resources (resource conservation technologies) and measures to manage water and risk (water and risk management measures) (Sharma 2013; Alauddin and Sarker 2014; Dagar et al. 2012; Pathak et al. 2014; Sapkota 2015; Tadesse et al. 2015 and Tripathi and Mishra 2017).

Traditional or experiential knowledge evolves over time in response to risks, and farming and rural communities adopt a range of adaptation strategies and practices based on their farming experiences, such as in Africa (Nyong et al. 2007; Bryan et al. 2009; Mertz et al. 2009; Deressa et al. 2011).

The farmers in the sample adopted practices such as paddy PR varieties, paddy LL, paddy DSR, wheat ZTW, and wheat improved varieties.

Paddy PR varieties When climatic conditions change, only some varieties allow for crops to be produced sustainably, and it is important to identify these varieties. An HYV that can withstand weather variability and multiple abiotic and biotic stresses is ideal. Punjab Agricultural University has introduced PR 126 and PR 121; these early maturing varieties can conserve groundwater and withstand climate events—the emergence of pests, or the sudden onset of frost or drought—that severely impact agricultural production.

Paddy LL Farmers level their land before puddling; using laser land levellers would help them level their land precisely, and raise the efficiency of water use and of other farm inputs, and thus help to mitigate the effects of climate change.

Direct seeded rice (DSR) Introduced in 2009–10 as an alternative to conventional manual puddled transplanted rice (Awan et al. 1989; Mitchell et al. 2004; Bhullar et al. 2018), DSR reduces methane emissions, and the demand for water and human labour, and significantly influences climate change.

Zero tillage wheat (ZTW) After the farmers harvest a crop, they burn the straw in their hurry to sow the next wheat crop. But the crop residue is full of essential plant nutrients, and burning it destroys the nutrients and sulphur and pollutes the environment. An alternative is planting crops in previously unprepared soil, known as zero tillage wheat (ZTW), zero till, no till, or direct planting, and it is being developed by the Indian Council of Agricultural Research (ICAR) and state agricultural universities (SAU).

Improved varieties of wheat The improved varieties of wheat, such as HD 2967 and HD 3086, can resist brown rust, but they are susceptible to new races of yellow rust.

Optimal plans for climate-resilient technologies

We introduced crop activities to the area—under technically feasible limits—to determine the optimum production plan. The resources are limited, the objectives and constraints variable, and the ways to maximize profits several; and we use a mathematical programming model to determine the optimal crop or land use plan.

Cropping pattern of sample farmers

Climate change and variability endanger crops; to mitigate the risks to the paddy crop, the farmers in the sample take measures at the farm level. On the basis of these measures, we subdivided the area under paddy into paddy PR VAR, Paddy LL, paddy DSR, and paddy (conventional).

Under the existing cropping pattern, paddy LL occupied 24.73% of the area under paddy (the largest percentage); paddy (conventional) occupied 16.67% of the kharif cropped area. Paddy was the major kharif crop grown, on about 57% of the total kharif area, and wheat the major rabi crop, on 70% of the total rabi cropped area (Table 3).

Maize was the next most important kharif crop, grown on 15% of the area. Potato, an important rabi crop, was grown on about 12% of the cropped area. The farmers in the sample did not grow any other vegetable. Among pulses, summer moong occupied only a marginal area. Sugarcane occupied 6–7% of the cropped area in the cropping pattern of the farmers in the sample.

We worked out the availability of water for irrigation per farm: on average, about 20,636 m^3 of water was used per hectare to irrigate all the crops in the existing plan. Paddy (conventional), which consumes about 40% more water than paddy DSR, required about 13,701 cu m of water per hectare, the highest. Conventional wheat required 2,450 cu m, and wheat sown with improved varieties required the least.

Comparative profitability

Variable costs include the expenditure on

- seeds, manures, fertilizers, and insecticides;
- irrigation and machine charges (owned and hired);
- charges for labour—attached, casual, and hired, and the imputed value of family labour;
- marketing and transportation costs; and
- miscellaneous expenses.

Table 3 Cropping pattern and irrigation requirement of different crops under existing cropping pattern of sample farmers, Punjab, 2016–17

Crop	Area (ha)	Percentage of total cultivated area	Irrigation water requirement (m^3/ha)
Kharif			
Paddy PR VAR	0.20	10.75	12,702
Paddy LL	0.46	24.73	10,989
Paddy DSR	0.09	4.84	8,262
Paddy (conventional)	0.31	16.67	13,701
Cotton	0.10	5.38	3,055
Maize	0.28	15.05	2,763
Summer moong	0.09	4.84	1,516
Sugarcane	0.12	6.45	8,669
Fodder	0.21	11.29	2,900
Total Kharif cropped area	1.86		
Rabi			
Wheat improved VAR	0.18	10.34	2228
Wheat ZTW	0.25	14.37	2302
Wheat (conventional)	0.79	45.40	2450
Potato	0.21	12.07	3844
Sugarcane	0.12	6.90	8669
Rabi fodder	0.19	10.92	7600
Total rabi cropped area	1.74		

The variable cost was highest for paddy PR VAR (INR 41,012 per hectare), double that of the wheat crop; the variable cost of cultivating maize was INR 38,768. The operational cost of the potato crop, which occupies the field for about 3 months, was nearly INR 1 lakh per hectare (the highest). Sugarcane is a perennial crop, but its operational cost was INR 72,653.

The returns to fixed farm resources were high from paddy DSR (INR 74,659.92 per ha), due to large saving of labour at the time of planting; it was the lowest in paddy conventional (INR 68,918.91). Wheat sown without tillage in the rabi season was the most profitable, as it yielded net returns over variable cost of INR 62,932 per hectare, which was 5.93% higher than conventional wheat. Paddy DSR yielded the highest returns of all kharif crops; wheat sown with improved varieties was the most profitable rabi crop (Table 4).

On the profitability aspect, all the climate-resilient technologies under paddy and wheat crop competed well with traditional paddy and wheat, and crop plans that save groundwater while retaining returns are needed.

Optimal crop plans

Plan 1 business-as-usual (BAU) scenario

We did not impose an irrigation constraint; shifting the area under paddy PR (54.84%) raised productivity and, therefore, net returns (by 5.12%), but it also consumed more water. Fodder is grown on all farm situations to meet the fodder requirements, and it is considered a fixed activity (Table 4). We retained the cultivated area in the existing production pattern under both kharif and rabi fodder.

We imposed some restrictions on the maximum area under paddy DSR considering that the returns on paddy DSR, cotton, and potato are high and considering also the market conditions, farmers' ability to bear risk, and the price volatility of the crop. The yield of improved varieties of wheat is higher than of local wheat varieties, and so we shifted the major area to improved varieties in the rabi season (Table 5).

Table 4 Net returns and variable costs of different crops in the study area, Punjab, 2016–17

(Rs/ha)

Crops	Operational cost	Gross returns	Returns over fixed farm resources
Paddy PR VAR	41012.18	112759.25	71,746.82
Paddy LL	37,415.26	107,280.43	69,865.17
Paddy DSR	28,417.38	103,077.30	74,659.92
Paddy (conventional)	36,816.49	105,735.40	68,918.91
Cotton	64,937.50	109,250.00	44,312.50
Maize	38,767.50	73,500.00	34,732.50
Summer Moong	28,928.00	56,662.00	27,734.00
Kharif fodder	32,804.00	53,300.00	20,496.00
Sugarcane	72,653.00	265,500.00	192,847.00
Wheat improved VAR	22,429.40	85,361.00	62,932.00
Wheat (ZTW)	21,678.62	84,215.63	62,537.01
Wheat	23,118.22	82,526.80	59,408.58
Potato	107,565.00	165,467.00	57,902.00
Rabi fodder	37,326.00	61,556.00	24,230.00

Table 5 Optimal crop plans for farm level climate adaptation strategies among the sample farmers, Punjab, 2016–17

Crop	Existing production pattern	Optimal Plan I	Optimal Plan II	Optimal Plan III
Kharif				
Paddy PR VAR	0.20 (10.75)	1.02 (54.84)	0.40(21.51)	0.32(17.20)
Paddy LL	0.46(24.73)	0.21(11.29)	0.46(24.73)	0.46(24.73)
Paddy DSR	0.09(4.84)	0.20(10.75)	0.20(10.75)	0.20(10.75)
Paddy (Conventional)	0.31(16.67)	0.00(0.00)	0.07(3.76)	0.00(0.00)
Cotton	0.10(5.38)	0.10(5.38)	0.10(5.38)	0.10(5.38)
Maize	0.28(15.05)	0.00(0.00)	0.30(16.13)	0.45(24.19)
Summer Moong	0.09(4.84)	0.00(0.00)	0.00(0.00)	0.00(0.00)
Sugarcane	0.12(6.45)	0.12(0.00)	0.12(6.45)	0.12(6.45)
Kharif Fodder	0.21(11.29)	0.21(11.79)	0.21(11.29)	0.21(11.29)
Total Kharif cropped area	1.86	1.86	1.86	1.86
Rabi				
Wheat Improved VAR	0.18(10.34)	1.33(76.44)	1.08(62.07)	1.08(62.07)
Wheat ZTW	0.25(14.37)	0.00(0.00)	0.25(14.37)	0.25(14.37)
Wheat	0.79(45.40)	0.00(0.00)	0.00(0.00)	0.00(0.00)
Potato	0.21(12.07)	0.10(5.75)	0.10(5.75)	0.10(5.75)
Sugarcane	0.12(6.90)	0.12(6.90)	0.12(6.90)	0.12(6.90)
Rabi Fodder	0.19(10.92)	0.19(10.92)	0.19(10.92)	0.19(10.92)
Total Rabi cropped area	1.74	1.74	1.74	1.74
RFFR	209,327.64	220,047.40	216,759.40	211,425.20
Increase in returns		5.12	3.55	1.24
Water use (cu m/ha)	20,614	23,700	20,301	18,752
Water saving (%)		-14.97	1.52	9.82

Notes: Sugarcane being a perennial crop, its area has been counted in rabi season as well

Plan – I: This plan is without irrigation constraint (business-as-usual); Plan II: Kharif water constraint along with area restrictions; Plan – III: Kharif water availability decreased by 10%; Figures within the parentheses indicate percentage to cropped area

Plan 2

We imposed constraints on irrigation in the kharif season. Maize requires less of irrigation than paddy, and so we shifted a major chunk of the area to maize. Maize covered 16.13% of the area in Plan 2, though it was not optimal in Plan 1, and the area under paddy fell from 77% in Plan 1 to 61% in Plan 2.

The returns on alternative crops are much less than on paddy; even so, the returns in Plan 2 increased by 1.49% over Plan 1, because the area shifted from conventional paddy varieties to climate-resilient technologies (paddy LL, paddy DSR, and paddy PR VAR). In the rabi season, the area shifted to wheat ZTW (0.25 ha), which helped in increasing returns as well as managing the paddy residue. Restricting the area cultivated with paddy PR VAR to 1 hectare per farm in Plan 2 shifted the area to paddy LL (0.46 ha), raising the net returns by 3.55% and savings 1.52% of groundwater.

Plan 3

We considered the percentage overdraft of the groundwater of the villages in the sample as a criterion for making Plan 3. Compared to Plan 2, the water usage fell 10%, the area under paddy fell from 61% to 53%, and the area under maize in the kharif season rose from 16% to 24%. In the rabi season, the area under wheat improved VAR shifted 62% and under ZTW 14.4%, but productivity was not affected. The RFFR increased by only 1.23%, but water use fell 9.82%.

Evaluation of optimal crop plans: a macro perspective

The paddy–wheat cropping pattern in Punjab is more profitable than other crops, and the production and marketing risks minimal. But the groundwater level in Punjab is falling fast; and farmers use climate-resilient technologies and techniques to maximize their net returns, such as managing water resources sustainably and using better crop varieties (paddy PR VAR and wheat improved VAR) and using irrigation water efficiently (paddy DSR and paddy LL, wheat ZTW).

On this rationale, the optimal crop Plan 3 of this micro-level study can be extended to the entire state by applying the same proportions to its net sown area. Under Plan 3, improved varieties of paddy will be planted over 7.02 lakh hectares and paddy DSR over 4.44 lakh hectares. Paddy is grown on 75% of the cultivated area of the state, but the area under paddy in the existing cropping pattern in the sample selected for this study is 57% of the kharif cropped area; it fell to 53% in Plan 3. Raising the acreage of maize by 24% to 9.91 lakh hectares will save 3.42 bcm of water, but not affect net returns, indicating that the trade-off between water use and net returns is favourable.

From the macro perspective, the proportions of the net sown area under the crop activities in Plan 3 will save water and benefit farmers and society. To reduce the impact of climate change and variability—while maintaining productivity and net income—it is necessary to adopt better crop varieties, irrigation management options, and climate-resilient on-farm technologies and adaptation strategies.

Conclusions and policy implications

To improve their net returns, the farmers of the study area practise a cropping pattern that saves groundwater. This study used a linear programming model to arrive at the optimal cropping pattern for maximizing net returns in Punjab.

This study identified five farm-level adaptation strategies: adopting early maturing varieties in paddy (PR VAR); paddy fields levelled with laser leveller (paddy LL); paddy sown directly in the fields without transplanting (paddy DSR); the cultivation of improved varieties of wheat; and the cultivation of wheat with no tillage.

A shift in the area under paddy PR (54.84%) in Plan 1 raised productivity and improved the net return by 5.12%. Imposing area restriction on paddy PR VAR in the alternative, Plan 2, up to 1 hectare on each farm resulted in the shift of the paddy area to paddy LL (0.46 ha), improving the net returns from crop production by 3.55% and saving groundwater by 1.52%.

Punjab draws 34.17 bcm of water; the draft can be reduced by 3.42 bcm by reducing the area under paddy from 57% to 53%, increasing the area under maize in the kharif season from 16% to 24%, and growing improved varieties of wheat. Using laser levellers and DSR would improve the water use efficiency of irrigation and also reduce the excessive use of energy and the risk of an imbalance in the supply and demand of water. Water may be saved also by growing short-duration varieties, instead of long-duration varieties such as Pusa 44; growing short-duration PR varieties also makes it easier to manage the paddy straw.

Farmers must adopt climate-smart practices at the farm level. Increasing their capacity to adopt these practices is the need of the hour. Building farmers' capacity to adopt climate-smart practices, by promoting strong linkages between research, extension services, insurance, and institutional support, will help to make the agriculture sector in Punjab sustainable in the long term.

References

Awan, I U, H K Alizai, and F M Chaudhry 1989. Comparative study of direct seeding and transplanting methods on the grain yield of rice. *Sarhad Journal of Agriculture* 5 (2): 119–124. https://agris.fao.org/agris-search/search.do?recordID=PK8901112

Bhullar, M S, Sukhpal Singh, Sunny Kumar, and Gurjeet Gill 2018. Agronomic and economic impacts of direct seeded rice in Punjab. *Agricultural Research Journal* 55 (2): 236–242. https://dx.doi.org/10.5958/2395-146X.2018.00038.8

Bryan, E, T T Deressa, G A Gbetibouo, and C Ringler. 2009. Adaptation to climate changes in Ethiopia and South Africa: options and constraints. *Environmental Science and Policy* 12 (4): 413–426. https://dx.doi.org/10.1016/j.envsci.2008.11.002

Bundesanstalt für Geowissenschaften und Rohstoffe (BGR) and the Geological Survey of Denmark and Greenland (GEUS). 2008. *Groundwater and climate change: challenges and possibilities*, edited by Friedrich Hetzel, Vanessa Vaessen, Thomas Himmelsbach, and Wilhelm Struckmeier (BGR) and Karen G Vilholth (GEUS). https://www.bgr.bund.de/EN/Themen/Wasser/Produkte/Downloads/groundwater_climate_change_pdf.pdf?__blob=publicationFile&v=3

Burke, J J, C Sauveplane, and M M President. 1999. Groundwater management and socio-economic responses. *Natural Resources Forum* 23 (4): 303–313. https://dx.doi.org/10.1111/j.1477-8947.1999.tb00918.x

Dagar, J C, A K Singh, R Singh, and A A Arunachalam. 2012. Climate change vis-à-vis Indian agriculture. *Annals of Agricultural Research New Series* 33 (4): 189–203. https://www.researchgate.net/publication/285036618_Climate_change_vis-a-vis_Indian_agriculture_Climate_change_vis-a-vis_Indian_agriculture

Deressa, T T, R M Hassan, and C Ringler. 2011. Perception and adaptation to climate change by farmers in the Nile basin of Ethiopia. *The Journal of Agriculture Science* 149 (1): 23–31. https://dx.doi.org/10.1017/S0021859610000687

Dhaka, B L, K Chayal, and M K Poonia. 2010. Analysis of farmers' perception and adaptation strategies to climate change. *Libyan Agriculture Research Center Journal International* 1 (6): 388–390. https://www.researchgate.net/publication/267384377_Analysis_of_Farmers'_Perception_and_Adaptation_Strategies_to_Climate_Change

Ghuman, R S. 2017. Water use scenario in Punjab: beyond the Sutlej–Yamuna link canal. *Economic and Political Weekly* 52 (3): 34–37. https://www.epw.in/journal/2017/3/punjab%E2%80%94exploring-prospects/water-use-scenario-punjab.html

GOP. 2011. *Block–Wise Abstract of Ground Water Estimates*, Water Resources Directorate, Punjab, Chandigarh.

Intergovernmental Panel on Climate Change (IPCC). 2001. Working Group II, third assessment report of the Intergovernmental Panel on Climate Change, edited by J J McCarthy, O F Canziani, N A Leary, D J Dokken, and K S White, Cambridge University Press, Cambridge (UK) and New York (USA), 981–996. https://www.ipcc.ch/site/assets/uploads/2018/05/SYR_TAR_full_report.pdf

Intergovernmental Panel on Climate Change (IPCC). 2014. Degrees of change: the IPCC's projections for future temperature rise. https://www.carbonbrief.org/degrees-of-change-the-ipccs-projections-for-future-temperature-rise

Izauralde, R C, N J Rosenberg, R A Brown, and A M Thomson. 2003. Integrated assessment of Hadley Centre (HadCM2) climate change impacts on agricultural yield and irrigation water supply in the conterminous United States: part II. Regional agricultural production in 2030 and 2095. *Agriculture Forest Meteorology* 117 (1&2): 97–122. https://dx.doi.org/10.1016/S0168-1923(03)00024-8

Jain, R, I Kingsly, R Chand, A P Kaur, S S Raju, S K Srivastava, and J Singh. 2017. Farmers and social perspective on optimal crop planning for ground water sustainability: a case of Punjab state in India. *Journal of the Indian Society of Agricultural Statistics* 71 (1): 75–88. https://www.researchgate.net/publication/330881984

Jain, R, L Malangmeih, S S Raju, S K Srivastava, I Kingsly, and A P Kaur. 2018. Optimization techniques for crop planning: a review. *Indian Journal of Agricultural Sciences* 88 (12): 1826–1835. https://www.researchgate.net/publication/329736318

Jain, R, S S Raju, I Kingsly, S K Srivastava, A P Kaur, and J Singh. 2015. *Manual on methodological approach for developing regional crop plan*. ICAR-National Institute of Agricultural Economics and Policy Research, New Delhi. https://krishi.icar.gov.in/jspui/bitstream/123456789/827/1/Manual%20on%20RCP.pdf

Kaur, Baljinder. 2011. Impact of climate change and cropping pattern on ground water resources of Punjab. *Indian Journal of Agricultural Economics* 66 (3): 373–387. https://www.researchgate.net/publication/289779894

Kaur, Baljinder, K Vatta, and R S Sidhu. 2010. Optimal crop plans for sustainable water use in Punjab. *Agricultural Economics Research Review* 23 (2): 273-284. https://dx.doi.org/10.22004/ag.econ.96936

Kaur, Baljinder, K Vatta, and R S Sidhu. 2015. Optimizing irrigation water use in Punjab agriculture: role of crop diversification and technology. *Indian Journal of Agricultural Economics* 70 (3): 307–318. https://dx.doi.org/10.22004/ag.econ.230064

Kumar, Sunny, and Baljinder Kaur. 2019. Impact of climate change on the productivity of rice and wheat crops in Punjab. *Economic and Political Weekly* 54 (46): 38–44. https://www.epw.in/journal/2019/46/special-articles/impact-climate-change-productivity-rice-and-wheat.html

Mertz, O, C Mbow, A Reenberg, and A Diouf. 2009. Farmers' perceptions of climate change and agricultural adaptation strategies in rural Sahel. *Environmental Management* 43 (9): 804–816. https://dx.doi.org/10.1007/s00267-008-9197-0

Mitchell, J, S Fukai, and J Basanayake. 2004. Grain yield of direct seeded and transplanted rice in rainfed lowlands of South-East Asia. Paper presented at 'New Directions for a Diverse Planet', 4th International Crop Science Congress in conjunction with the 12th Australian Agronomy Conference and the 5th Asian Crop Science Conference, 26 September to 1 October, Brisbane, Australia; also chapter in book titled *New directions for a diverse planet*, edited by R A Fisher. https://www.cabdirect.org/cabdirect/abstract/20193228254

Nyong, A, F Adesina, and B Osman Elasha. 2007. The value of indigenous knowledge in climate change mitigation and adaptation strategies in the African Sahel. *Mitigation and Adaptation Strategies for Global Change* 12: 787–797. https://dx.doi.org/10.1007/s11027-007-9099-0

Panda, S N, M P Kaushal, and S D Khepar. 1983. Irrigation planning of a command area in Punjab: an application of deterministic linear programming. *Journal of Agricultural Engineering* XX (2): 47–60. https://isae.in/uploads/jae-aet/160085282947-60_irrigation_planning_of_a_command_area_in_punjab.pdf

Pathak, H, P Pramanik, M Khanna, and A Kumar. 2014. Climate change and water availability in Indian agriculture: impacts and adaptation. *Indian Journal of Agricultural Sciences* 84 (6): 671–679. https://www.researchgate.net/publication/263057821

Punjab Agricultural University (PAU). 2018. *Agricultural handbook*, 3–6.

Sankhayan, P L, and H S Cheema. 1991. Using linear programming models for generating optimum farm plans—an expository analysis. *Indian Journal of Agricultural Economics* 46 (4): 601–612. https://dx.doi.org/10.22004/ag.econ.272698

Sapkota, T B, M L Jat, J P Aryal, R K Jat, and A Khatri-Chhetri. 2015. Climate change adaptation, greenhouse gas mitigation and economic profitability of conservation agriculture: some examples from cereal systems of Indo-Gangetic Plains. *Journal of Integrative Agriculture* 14 (8): 1524–1533. https://dx.doi.org/10.1016/S2095-3119(15)61093-0

Sarkar, A, and Arjit Das. 2014. Groundwater irrigation–electricity–crop diversification nexus in Punjab: trends, turning points, and policy initiatives. *Economic and Political Weekly* 49 (52): 64–73. https://www.epw.in/journal/2014/52/review-rural-affairs/groundwater-irrigation-electricity-crop-diversification-nexus

Sharma, B R. 2013. Impact of climate change on water resources and potential adaptations for Indian agriculture. *Annals of Agricultural Research* 34 (1): 1–14. https://hdl.handle.net/10568/40311

Sidana, B K. 2008. *Optimal crop plans for sustainable water use in Punjab*. PhD thesis, Department of Economics and Sociology, Punjab Agricultural University, Ludhiana, Punjab.

Singh, N, C Bantilan, K Byjesh, S Nedumaran, V U M Rao, B Venkateswarulu, F Niranjan, W Jayatilaka, U K Deb, P Q Ha, and P Suddhiyam. 2015. Moving along adaptation pathways toward grass-root resilience: A synthesis, in *Climate change challenges and* *adaptations at farm-level: case studies from Asia and Africa*, edited by N P Singh, C Bantilan, K Byjesh, S Nedumaran, 197–211. CABI, UK.

Singh, R D, and C P Kumar. 2009. *Impact* of *climate change on groundwater resources*. Paper presented at the Proceedings of 2nd National Ground Water Congress, 22 March 2010. https://www.researchgate.net/publication/215973855_

Sophocleous, M. 2003. Environmental implications of intensive groundwater use with special regard to streams and wetlands, in *Intensive use of groundwater: challenges and opportunities*, edited by Ramón Llamas and Emilio Custodio. https://fundacionbotin.org/89dguuytdfr276ed_uploads/Observatorio%20Tendencias/PUBLICACIONES/LIBROS%20SEM%20INTERN/intensive%20use%20groundwater/cap04-intensiveuse.pdf

Tadesse, M A, B A Shiferaw, and O Erenstein. 2015. Weather index insurance for managing drought risk in smallholder agriculture: lessons and policy implications for sub-Saharan Africa. *Agricultural and Food Economics* 3 (1): 26. https://dx.doi.org/10.1186/s40100-015-0044-3

Tompkins, E L, and W N Adger. 2003. *Building resilience to climate change through adaptive management of natural resources.* Tyndall Centre Working Paper No 27, Tyndall Centre for Climate Change Research. https://www.researchgate.net/publication/228816846_Building_Resilience_to_Climate_Change_Through_Adaptive_Management_of_Natural_Resources

Tripathi, A, and A K Mishra. 2017. Knowledge and passive adaptation to climate change: an example from Indian farmers. *Climate Risk Management* 16 (9): 195–207. https://dx.doi.org/10.1016/j.crm.2016.11.002

Vatta, K, M S Sidhu, and Amanpreet Kaur. 2013. *Pattern of growth and emerging challenges for Punjab agriculture*. Draft report submitted to the United Nations Environment Programme (UNEP). https://dx.doi.org/10.13140/RG.2.2.29010.79044

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