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Gross economic efficiency of water use in agriculture and water-saving farm plans for Punjab

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Abstract The present study attempts to estimate the gross economic efficiency (GEE) of the paddy–wheat–milk production system in Punjab and work out the water use–efficient combination of crops and dairy enterprises. The study is based on secondary data from published and unpublished sources. The GEE of water use in paddy–wheat–milk production ranged from Rs. 22.47 per cubic metre (m^3) to Rs. 60.46 per m^3. The study revealed that diversifying the irrigated area under cereal crop towards green fodder crops can improve the output value and the efficiency of groundwater use.

Keywords Paddy–wheat–milk system, water use efficiency, Punjab

JEL classification D61, Q18, Q25

1 Introduction

The role of agroecological, institutional and technological factors in enabling a phenomenal growth in agricultural productivity and production – the green revolution – in Punjab, a state in India, is well documented, as is the transformation of its rural economy. Its contribution to the food security of the nation led the state to be heralded as the 'Granary of India' and become for all Indian states a role model of agricultural development until it started experiencing the negative externalities of the green revolution. The growth of agriculture in Punjab, achieved through intensive agricultural practices, is now being criticized for leveraging its success on the environment (Jalota et al. 2007). The depletion over time of natural resources, especially groundwater, has endangered the sustainability of the state's agriculture. The demand for irrigation water in the state is estimated at 4.76 million hectare metres (mhm) per annum, 1.28 mhm more than the supply from canal and groundwater resources (3.48 mhm). To meet this annual net deficit, tube wells are used to withdraw groundwater (Singh et al. 2012); this over-exploitation is reported to be 72% higher than the sustainability limit of 20 billion cubic metres (bcm) per annum (Srivastava et al. 2015), and it has pushed the groundwater table below the critical depth of 10 metres in many areas.

The over-exploitation of groundwater can be reduced by improving the water use efficiency of crops – 'more crop per drop' – and the diversification of agriculture via allied agricultural activities. Any drastic diversification is unlikely, because the paddy–wheat system in Punjab is critical to the national food security, but a technically and economically feasible option is an optimal combination of paddy–wheat rotation with allied agricultural enterprises like dairying, an

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important economic enterprise. The intensification of dairy production would require shifting agricultural area from cereals to green fodder crops. This study brings out the inter-district variations in Punjab in the economic efficiency of water use for production of paddy, wheat and milk. It also suggests an economically optimal, water use–efficient paddy–wheat–dairy farm plan.

2 Materials and methods

Water productivity is the total amount of water needed to generate unit amount (or value) of produce (Molden 1997). Analysing crop water productivity is a complex activity; no single parameter can determine the efficiency of water use in crop production. The literature uses two major parameters of crop water productivity: the physical productivity of water expressed in kilograms of crop per cubic metre of water diverted or depleted; and the net or gross present value of the crop produced per cubic metre (Rs./m^3) of water, or the economic efficiency of water use (Kijne et al. 2003).

2.1 Estimation of gross economic efficiency (GEE)

The gross economic efficiency (GEE) of water use in paddy, wheat and milk production was estimated as follows.

Crop production

$$\text{GEE (Rs/m}^3) = \frac{\text{Production} \times \text{Farm harvest price}}{\left(\text{Total CWU}_{\text{crop}}\left(\text{m}^3/\text{ha}\right) \times \text{Net swon area}\right)} \quad \ldots(1)$$

where CWU_{crop} is the consumptive water use (CWU) of crop, or volume of water consumed by the crop to meet all its requirements.[1] This study adopts the internationally accepted estimation methodology (Allen et al. 1998; Chapagain & Hoekstra 2004; Mekonnen & Hoekstra 2012).

$$CWU_{Crop} = CWU_{rainfall} + CWU_{irrigation} \quad \ldots(2)$$

$$CWU_{rainfall} = \text{Min}\,(ET_p, P_{eff}) \quad \ldots(3)$$

When irrigation meets part of the deficit crop water requirement, the irrigation CWU is the net evapotranspiration, which is the difference between the actual evapotranspiration (ET_p) and the effective part of rainfall at the root zone (P_{eff}).

$$CWU_{irrigation} = ET_p - P_{eff} \quad \ldots(4)$$

The estimation of ET_p requires information on crop coefficient,[2] duration and reference evapotranspiration in crop growth periods (initial, development, mid- and late stages) and P_{eff} is based on the daily 75% exceedance (P75)[3] probability of rainfall during crop growth.

Milk production

Two types of dairy animals are reared in Punjab – cows and buffaloes. The productivity and feeding of crossbred cows are quite different from that of local (nondescript) cows; hence, the GEE of milk production was worked out separately for crossbred cows, local cattle and buffaloes.

$$\text{GEE (Rs/m}^3) = \frac{\text{Production} \times \text{Farm gate prices}}{\left(\text{Total CWU}_{\text{dairy}}\left(\text{m}^3/\text{animal}\right) \times \text{No. of dairy animals}\right)} \quad \ldots(5)$$

where CWU_{dairy} is consumptive water use in dairying comprising direct (drinking, bathing and servicing) and indirect (feed and fodder) components. The estimates of direct water use by dairy cattle (85 litre/day) have been taken from the data on animal experiments from the Livestock Research Centre of National Dairy Research Institute, Karnal. The dairy animals in Punjab are akin to the animals used in the experiments in terms of their productivity level and the management practices followed in rearing the animals.

The indirect component of CWU comprises water required for producing feed and fodder – dry fodder, green fodder and concentrate. The principal source of dry fodder is crop residue, largely wheat straw. The CWU of crop residue was estimated by apportioning the water use of specific crops based on

[1] 'Consumptive water use' (CWU) signifies actual usage, and it is distinct from 'consumptive water requirement' (CWR), a crop's agronomic requirement. A crop's CWU equals its CWR when it adequately meets its water requirements from rainfall and irrigation. In Punjab, 100% of agriculture is irrigated, and these terms have been used interchangeably.

[2] The crop coefficient incorporates crop characteristics and averaged effects of soil evaporation; it integrates the effect of both crop transpiration and soil evaporation.

[3] P75 refers to the amount of rainfall exceeded 75% of the time.

the yield weighted by the prices of the main crop and its residue.

$$\text{CWU}_{\text{product}}=(\alpha_i \times \text{CWU}_{\text{crop}}) \quad \ldots(6)$$

where $\alpha_i = q_i p_i / \Sigma q_i p_i$, and q_i and p_i are conversion ratios and prices of main product or by-product, respectively.

The CWU for cultivated fodder crops is estimated in the same way as for other crops. The ingredients of concentrate feed (mustard cake, rice bran) are derived from the main crops grown on the farm. Here apportioning has been done using the conversion ratio of main product and meal to work out the CWU of concentrates.

2.2 Data

This study is based on secondary data collected from published and unpublished sources (Annexure 1). The water productivity of crop and milk output was estimated for all the districts in the state of Punjab.

2.3 Analytical framework

Taking a cue from an earlier study (Amarasinghe et al. 2010), the linear programming (LP) technique was used to assess the optimal cropping pattern and livestock combination for maximizing the value of the gross agricultural output while maintaining the total groundwater CWU below the sustainable groundwater supply limit. The optimal cropping pattern considers the percentage of paddy, wheat and fodder area in the monsoon and winter seasons. The optimal livestock combination considers the minimum number of crossbred cattle and buffaloes to be raised on average landholding size. This analysis considers only paddy and forage crops in the monsoon season and wheat and forage crops in the winter season (Table 1).

Constraint maximization of value of gross output (VOP)

$$\text{VOP} = \text{VOP}_r + \text{VOP}_w + \text{VOP}_m \quad \ldots(7)$$

Objective function

$$\text{VOP}_r = A_r \times Y_r \times P_r \quad \ldots(8)$$

$$\text{VOP}_w = A_w \times Y_w \times P_w \quad \ldots(9)$$

$$\text{VOP}_m = \text{CB} \times M_{cb} \times P_{cb} + \text{BU} \times M_{bu} \times P_{bu} \quad \ldots(10)$$

$$A_r = \text{NIA} \times \%A_r \quad \ldots(11)$$

$$A_w = \text{NIA} \times \%A_w \quad \ldots(12)$$

Substituting equations (11) and (12) in equations (8) and (9) and rearranging, the objective function can be written as:

$$\text{VOP} = A \times (\%A_r \times Y_r \times P_r + \%A_w \times Y_w \times P_w) + (\text{CB} \times M_{cb} \times P_{cb} + \text{BU} \times \text{M}_{bu} \times P_{bu}) \quad \ldots(13)$$

The main constraints imposed are total groundwater CWU, total dry fodder consumption and total green fodder consumption.

Table 1. Description of variables

Variable	Description
VOP	Value of gross output (million rupees)
VOP_r	Value of output from paddy (million rupees)
VOP_w	Value of output from wheat (million rupees)
VOP_m	Value of output from milk (million rupees)
NIA	Net irrigated area (mha)
P_r, P_w, P_{cb}, P_{bu}	Prices of rice, wheat and milk of crossbred cattle and buffaloes (Rs./ton)
$\%A_r$,$\%A_w$,$\%A_{fk}$,$\%A_{fr}$	Percentage of net irrigated area (NIA) under rice, wheat and green fodder crops in the kharif and rabi seasons (%)
Y_r, Y_w, Y_{fk}, Y_{fr}	Yield of rice and wheat, and average yield of green fodder crops in the kharif and rabi seasons (tons/ha)
CB, BU	Milch crossbred cattle and buffaloes (number)
M_{cb}, M_{bu}	Milk productivity of cattle and buffaloes (tons/animal/year)
TGWCWU	Total groundwater CWU (mcm)
TDFCON	Total dry fodder consumption (tonnes)
TGFCON	Total green fodder consumption (tonnes)

Total groundwater consumptive water use (CWU)

$TGWCWU = S_i \times TGWCWU_i <$ Net water available for irrigation …(14)

i= paddy, wheat, kharif fodder, rabi fodder

The groundwater CWU in production of paddy, wheat and fodder crops should be within the sustainable limit of groundwater availability for irrigation purpose. The groundwater CWU was worked out from the $CWU_{irrigation}$ and the proportion of groundwater irrigation in total irrigated area in the given season. The constant in the constraint function – the net groundwater availability for irrigation – was computed by deducting the water draft for domestic and industrial use from the total net groundwater availability in the district.

Total dry fodder consumption

$TDFCON = DF_{cb} \times CB + DF_{bu} \times BU + DF_{other\ cattle} <$ dry fodder production …(15)

The production of wheat straw, which is the principal source of dry fodder, is sufficient to meet the annual consumption of dry fodder. The production of dry fodder is estimated as a proportion of straw output to grain production; it is 1:1 in the case of wheat. We estimated annual consumption from the average daily quantity of consumption of crossbred cattle (DF_{cb}) and buffaloes (DF_{bu}). A multiplier was used in equation (15). We computed the dry fodder consumption of other animals (comprising indigenous cattle, crossbred cows and buffalo of all ages and sex) by using a multiplier derived from the proportion of these animals to the milch crossbred cattle and buffaloes.

Total green fodder consumption

$TGFCON = GF_{cb} \times CB + GF_{bu} \times BU + GF_{other\ cattle} <$ green fodder production …(16)

The production of green fodder crops (sorghum, berseem, maize, oats, etc.) should be sufficient for feeding the total cattle and buffalo population so as to meet their annual consumption requirements. We computed the annual estimates of green fodder consumption from the average daily consumption pattern of crossbreds (GF_{cb}) and buffaloes (GF_{bu}); for other animals, we applied a methodology similar to the case of dry fodder. Other conditions in the maximization problem are $\%A_r > 0$, $\%A_w < 100\%$, $\%A_{fr} > 0\%$, $\%A_{fk} > 0$, CB > 0 and BU > 0. The minimum percentage of paddy is greater than zero; the percentage area under wheat is less than 100%. The percentage area under fodder crops is more than zero to fulfil the fodder requirement of animals.

3 Results and discussion

3.1 Water productivity

In the prevailing paddy–wheat–milk production system, wheat has the highest water productivity (1.75 kg/m^3) followed by milk (1.43 kg/m^3) and paddy (0.77 kg/m^3) (Table 2).

The inter-district variations in the water productivity of wheat are less than that of paddy. This study's estimates of the water productivity of paddy conform broadly with the estimated all-India water productivity of paddy, 0.50-1.10 kg/m^3 by Tuong & Bouman (2002). But, the water productivity of wheat seems to be higher in Punjab as compared to all-India average of 0.70 kg/m^3 (Kampman 2007). In comparison to China (0.59 kg/m^3), the performance in terms of water productivity is very poor (Zhu et al. 2004).

The rainy season in Punjab starts early in July and lasts until the end of September. Therefore, rainfall meets about 45% of the water requirement of paddy and irrigation sources contribute 92% of the CWU of wheat.

Table 2. Water productivity of paddy–wheat–milk in Punjab

Particulars	Paddy	Wheat	Milk
Mean (kg/m^3)	0.77	1.75	1.43
Range (kg/m^3)	0.52-0.93	1.46-1.94	0.89-1.98
Inter-district coefficient of variation (%)	15.39	7.99	18.11
Contribution of irrigation in total CWU (%)	54.18	91.59	81.70
Contribution of rainfall in total CWU (%)	45.82	8.41	18.30

Source: Authors' own calculations

Table 3. Gross economic water use efficiency of paddy and wheat

Districts	Share in area under paddy (%)	Gross economic water use efficiency of paddy (Rs. per m^3)	Share in area under wheat (%)	Gross economic water use efficiency of wheat (Rs. per m^3)
Amritsar	6.53	5.71	5.39	21.36
Barnala	3.73	9.66	3.26	19.24
Bathinda	3.58	8.88	7.14	17.16
Faridkot	3.58	8.97	3.32	19.51
Fatehgarh Sahib	3.05	9.58	2.41	20.14
Ferozpur	9.12	7.14	11.17	19.29
Gurdaspur	7.13	7.62	6.55	22.25
Hoshiarpur	2.63	8.00	4.37	18.37
Jalandhar	5.86	5.32	4.85	14.92
Kapurthala	4.19	7.95	3.12	20.09
Ludhiana	9.12	10.09	7.28	20.92
Mansa	2.63	7.99	4.82	21.24
Moga	6.17	9.96	4.99	20.38
Mohali	1.14	9.11	1.47	18.44
Muktsar	4.01	7.10	5.84	18.12
Nawanshahar	2.02	8.72	2.13	20.07
Patiala	8.30	8.20	6.72	16.67
Ropar	1.35	7.19	1.81	18.03
Sangrur	9.72	9.96	8.13	18.66
Tarn Taran	6.14	6.55	5.24	20.30

Source: Authors' own calculations
Note: Pathankot and Fazilka were part of Gurdaspur and Ferozepur, respectively, at the time of the study.

Fodder crops are raised under irrigated conditions; hence, irrigation is the predominant source of CWU for milk production. From the point of economic and environmental sustainability, the major concern is the productivity of irrigated water. The difference between total water productivity and irrigation water productivity is not very sharp in the case of wheat and milk, since irrigation meets 90% of the water requirement, but in the case of paddy its irrigation water productivity is higher than its total water productivity (of 0.77 kg/m^3).

3.2 Gross economic efficiency (GEE)

The GEE of paddy is substantially higher in Ludhiana (Rs. 10.09 per m^3) than in other districts (table 3). The GEE is lowest for Jalandhar (Rs. 5.32 per m^3) and Amritsar (Rs. 5.71 per m^3) because the yield of paddy is lower in Jalandhar (3.5 tons/ha) and Amritsar (2.6 tons/ha) than the state average (4.3 tons/ha). There is an immediate need for measures to improve the water use efficiency in these districts.

In the case of wheat, the GEE is highest in Gurdaspur (Rs 22.25 per m^3) and lowest in Jalandhar (Rs. 14.92 per m^3). The yield of wheat is less in Jalandhar (5.0 tons/ha) than in Ludhiana, Sangrur and Moga districts (5.4–5.5 tons/ha). The district of Ferozpur accounts for about 9% of paddy area and 11% of wheat area of the state, but its GEE is on the lower side; it is necessary to improve the water use efficiency of paddy and wheat in the district.

The water required in milk production changes by the type of animal as the feed intake depends on the type of animal and its productivity. The water productivity of milk is greater for crossbred and local cows than for buffaloes in physical terms (kg/m^3), but the inter-district

Table 4. Gross economic water use efficiency of milk

Districts	Share of milch animals (%)	Buffalo (Rs/m^3)	Crossbred (Rs/m^3)	Local cows (Rs/m^3)	Overall (Rs/m^3)
Amritsar	7.50	47.54	64.70	40.20	41.96
Barnala	2.64	56.13	42.19	53.02	53.02
Bathinda	4.47	37.31	35.87	45.79	43.21
Faridkot	2.61	71.02	42.91	62.05	63.02
Fatehgarh Sahib	3.08	33.36	25.89	35.08	34.38
Ferozpur	8.49	25.24	21.10	26.43	25.85
Gurdaspur	7.14	39.64	70.14	47.22	44.75
Hoshiarpur	5.18	34.05	26.57	32.69	32.92
Jalandhar	5.13	36.91	42.43	55.11	45.32
Kapurthala	4.30	61.71	71.91	24.14	29.64
Ludhiana	10.27	60.61	43.77	39.90	44.84
Mansa	3.74	48.88	42.24	56.91	55.19
Moga	4.56	46.64	44.42	41.48	42.64
Mohali	2.76	40.74	27.49	35.77	36.26
Muktsar	2.77	49.19	45.59	49.26	49.02
Nawanshahar	2.85	33.20	25.25	34.58	33.98
Patiala	6.36	34.53	29.01	36.61	35.95
Ropar	2.40	34.98	28.08	36.82	36.23
Sangrur	8.22	42.26	41.60	42.27	42.25
TarnTaran	5.52	61.50	79.23	44.04	46.91

Source: Authors' own calculations

variations in monetary terms are very sharp because of the differences in the price of buffalo and cow milk and composition of dairy herd (Table 4). In Tarn Taran district, for instance, the physical water productivity is the least for buffaloes and highest for local cows, but in monetary terms the situation is reverse, the gross economic water use efficiency for buffaloes (Rs. 61.50 per m^3) is 1.4 times higher than that of local cows. The dairy buffalo population of the district is over 500,000, but there are only 24,000 local dairy cows. The price of buffalo milk is 1.2 times that of cow milk. Similarly, in monetary terms the GEE in Faridkot is lower for crossbred cattle than for local cows and buffaloes; in physical terms it is the reverse. The aggregate estimates (aggregated over type of dairy animals) of GEE in milk production in a district are the weighted average of water productivity (in monetary terms) of different types of animals; the weights being value share of each type of animal in the total value of milk output in the district.

3.3 Water–efficient combination of crops and dairying

Having estimated the water productivity of paddy, wheat and milk for all the districts in the state, the overall GEE of water use was worked out as weighted average for each component, the weights being the value of output of these commodities in the district. In terms of overall GEE of water use, the most productive district is Faridkot (Rs. 60.46 /m^3) and the least productive district is Ferozepur (22.47 Rs/m^3) (Figure 1).

We develop water use–efficient farm plans for Ferozepur district. We also undertake an optimization exercise for Sangrur, as the groundwater exploitation situation is the most precarious there (Figure 2). The annual groundwater draft in Punjab is higher than the net annual groundwater availability in all the districts; however, in Sangrur, the annual groundwater draft is 264% higher than the net ground water availability of 1393 million cubic metres (mcm).

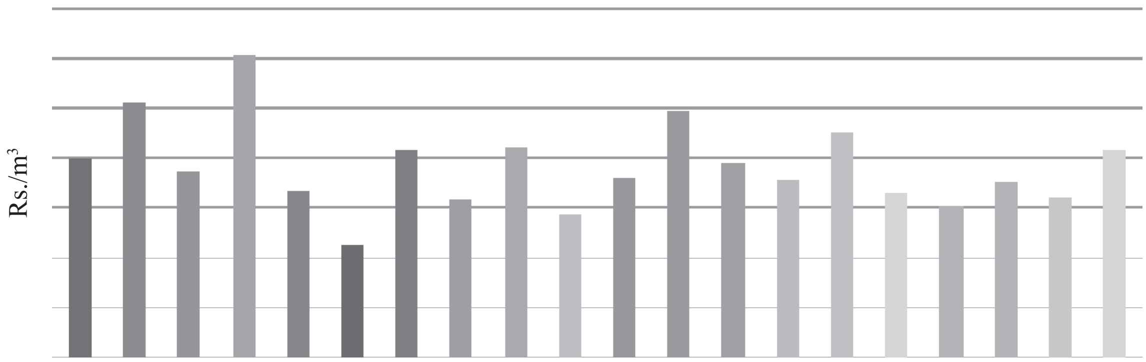

Figure 1. Aggregate gross economic efficiency (GEE) of water use for paddy–wheat–milk production
Source: Authors' own calculations

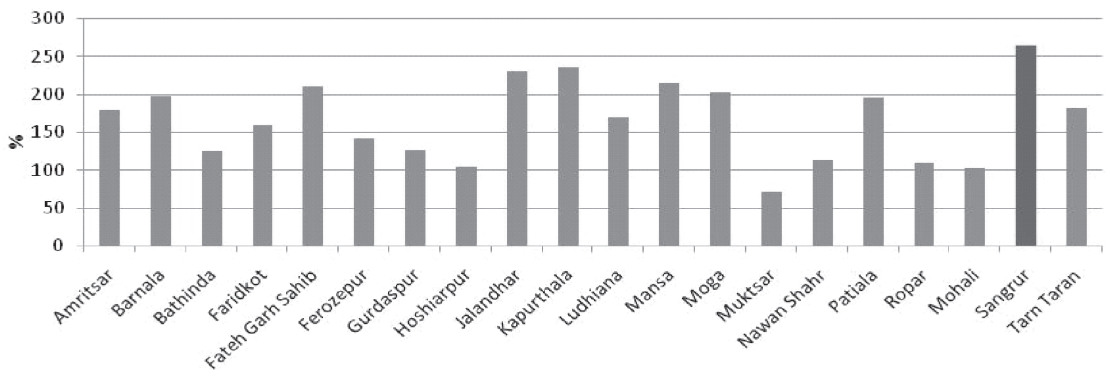

Figure 2. Stage of groundwater development
Source: CGWB, 2009[4]

Farm plan: Ferozepur

In Ferozepur district, the gross value of output can be maximized while fulfilling the water availability and other constraints when the area under rice is reduced from 92% to 77% in monsoon season and the number of milch crossbred and buffalo is increased from 2.5 to 5.5 on an average landholding size of 5.26 ha (Table 5). The area under wheat will have to remain unchanged to meet the dry fodder requirement of the existing and increased animal stock, but the fodder area will have to be increased from 8% to 23% for meeting the green fodder requirement in the monsoon season. This plan will raise the gross income per hectare of net irrigated area under the paddy–wheat–dairy combination 45.79% from the existing Rs. 107,000/ha to Rs. 156,000/ha, and it will save 33 mcm of water.

Farm plan: Sangrur

The estimated total CWU for irrigating paddy, wheat and fodder crops is 1821 mcm (Table 6), far in excess of its sustainable limit. Hence, in this district mere reallocation of irrigated cropped area among cereals and fodder crops cannot bring down the CWU to the 'safe' limit. This is reflected in the results of the quantitative analysis as well.

In the monsoon season, the area under paddy needs to be reduced drastically to 36% of net the irrigated area in the season from the existing level of 94% (Table 6). The area under monsoon fodder crops is to remain at 6% of the net irrigated area. This implies that more agricultural diversification is required in the monsoon season towards crops that consume less water. The loss in the value of output due to a decrease in the paddy area can be compensated by increasing the average number of milch animals from 2.8 to 4.4 for an average landholding size of 3.46 ha.

The green fodder requirement of the increased number of animals can be met by allocating 6% of the net

[4] CGWB (2009), Dynamics of Ground Water Resources of India, Ministry of Water Resources, Govt. of India.

Table 5. Water–efficient crop-dairy combination: Ferozpur district

Scenario	Monsoon season (% of NIA)		Winter season (% of NIA)		No. of lactating animals	Annual gross value of output per hectare of NIA (Rs thousand/ha)	Groundwater CWU (mcm)
	Rice	Fodder	Wheat	Fodder			
Baseline (2010-11)	0.92	0.08	0.93	0.07	2.5 (0.9cb) (1.6 bu)	107	1364
Optimal solution	0.77	0.23	0.93	0.07	5.5 (1.4 cb) (4.1 bu)	156	1331
Change from base	-0.15	+0.15	-	-	+3	+49	-33

Source: Authors' own calculations
Note: NIA, net irrigated area; CWU, consumptive water use; mcm, million cubic metre; bu, buffalo; cb, crossbred.

Table 6. Water–efficient crop-dairy combination: Sangrur district

Scenario	Monsoon season (% of NIA)		Winter season (% of NIA)		No. of lactating animals	Annual gross value of output per hectare of NIA (Rs in lakh/ha)	Groundwater CWU (mcm)
	Rice	Fodder	Wheat	Fodder			
Baseline (2010-11)	0.94	0.06	0.93	0.07	2.8 (0.3 cb) (2.5 bu)	175	1821
Optimum Output	0.36	0.06	0.94	0.06	4.4 (0.64 cb) (3.8 bu)	201	1347
Change from base	-0.56	0	+0.01	-0.01	+1.60	+26	-474

Source: Authors' own calculations
Note: NIA, net irrigated area; CWU, consumptive water use; mcm, million cubic metre; bu, buffalo; cb, crossbred.

irrigated area in each season to fodder crops. The gross income per hectare of net irrigated area from paddy–wheat–dairy combination will increase to Rs. 201,000/ha under this plan, 14.85% higher than the existing Rs. 175,000/ha, and 474 mcm of water can also be saved.

Other studies on the efficiency of water use in Punjab have also advocated that the area under paddy crop be reduced. Reducing the area under rice in Moga district and increasing the area under wheat and fodder, along with the intensification of dairy farming, can bring significant hydrological and financial benefits to Moga (Amarasinghe et al. 2010). To reduce the excessive pressure on groundwater resources in the state, the area under paddy should be reduced to 57.34% of the cultivated area at present from 70.65% (Baljinder et al. 2010). This would balance economic and environmental considerations.

A seasonal allocation model was developed to maximize net profit from crop water production in the canal command area under the Golewala distributary in the south-western plain region of Punjab (Paul et al. 2000). This model used deterministic dynamic programming to optimally allocate land and water resources to different crops. The complete shift in the area under mustard, and the minor shift in the area of gram and wheat towards barley, were reported to have the potential of doubling profits. The results call for a sea change in the existing cropping pattern.

4 Conclusions

The over-dependency on groundwater resources in Punjab over the past few decades and its unwise use for irrigation has had far-reaching impacts on the sustainability of agriculture and emerged as a serious concern in scientific and policy circles. It is now crucial that the entire state use water judiciously for cultivating crops, and immediate measures are required in districts like Jalandhar, Amritsar and Ferozpur where the GEE of paddy and wheat is very low. The results of this study suggest that reducing the area under paddy in Ferozepur, the least water productive district, and increasing the area under fodder crops during the monsoon would support a larger stock of milch crossbreds and buffaloes, increase the gross value of output by around 45% and save 33 mcm of water. In Sangrur, where groundwater exploitation has led to a precarious situation, the optimal farm plan would be to diversify in the monsoon towards crops that consume less water; for the average landholding of 3.46 ha, that would raise the average number of milch animals from 2.8 at present to 4.4.

Besides changes in the farm plans, various approaches and options to improve water use efficiency include, improving agronomic and irrigation management practice, like alternate wetting and drying (Tabbal et al. 2002); system of rice intensification (Thakur et al. 2010; Zhao et al. 2010); use of tensiometers (Hira et al. 2006, 2007); and direct plantation of paddy (Cabangon et al. 2002; Johnkutty et al. 2002; Singh et al. 2005). There is a need for a multi-pronged strategy encompassing improvement in productivity of alternative crops, increase in their prices and strengthening of market infrastructure (Baljinder et al., 2010).

The populist measures such as free water electricity have also been responsible for over-exploitation of groundwater resources. Pricing of water electricity should be based on long term environment consideration. Crop insurance would be another alternative. Punjab producers use irrigation water as part of their risk management to stabilize incomes across good and bad years. With crop insurance available to them, producers would be likely to reduce irrigation water use since there would be an additional source of income stability. Crop insurance could also be a useful complement to the removal of cheap water policies (Jalota et al., 2007). The real choices of options for enhancing water productivity would eventually depend on socio-economic factor prevailing in the region.

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Annexure 1. Data source of major variables for water productivity

Variable	Source
	Crop
Stages of crop growth periods Months and days of crop growth periods Crop coefficients	Department of Agronomy and Agro meteorology, Punjab Agricultural University, Ludhiana
Planting and harvesting weeks and dates	Punjab Agricultural University Ludhiana, Subject Matter Specialists of Krishi Vigyan Kendras
Latitudinal and longitudinal address of districts	World Atlas
Reference evapotranspiration (ET_0) Daily 75% exceedance probability of rainfall (P75)	Online World Water and Climate Atlas of IWMIhttp://www.iwmi.cgiar.org/resources/world-water-and-climate-atlas/
Planting and harvesting months	Comprehensive Scheme for Cost of Cultivation (unit record data)
	Milk
Yields and prices of main crop and by-product for conversion ratios of crops for apportioning	Comprehensive Scheme for Cost of Cultivation: unit record data
Information on fodder production Duration Favourable time of raising Average yield	Package of Practices (various issues) published by Punjab Agricultural University, Ludhiana
Drinking, bathing and servicing	Kar et al. (2016)
Feeding patterns	Primary field survey under projects led by Division of Dairy Economics, Statistics & Management, National Dairy Research Institute, with funding from National Agricultural Technology Project and Department of Animal Husbandry, Dairying & Fisheries, Govt. of India. Subject Matter Specialists and State Animal Husbandry Department (personal communication)