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A Study on Evolving Optimal Cropping Patterns in Groundwater Over-exploited Region of Perambalur District of Tamil Nadu

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Abstract

Falling groundwater tables and depletion of economically accessible groundwater resources would have major social and economic consequences. The present study has been taken up with the overall objective of evolving optimal crop plans to sustain the use of groundwater resources for irrigation. Perambalur district was purposively selected for the study as it mainly depends on groundwater for its irrigation. Linear programming technique was used to evolve optimal crop plans. The constraints identified were primarily irrigation water, besides land availability during the cultivating seasons and capital. Six typical farms were selected, one each for the open well, wells in tank command area and tubewell-irrigated farms in critical and over-exploited groundwater regime and also for semi-critical and safe groundwater regime. The results of the optimal crop plans derived showed that the irrigation water-use in the critical period could be reduced by 24.30, 4.54 and 51.71 hours of pumping in ordinary wells, wells in tank command area and tubewell-irrigated farms, respectively in critical and over-exploited groundwater regime sample farms. In the semi-critical and safe groundwater regime sample farms, the optimal crop plans revealed that the irrigation water-use in the critical period could be reduced by 4.61, 3.99, and 4.73 hours of pumping in ordinary wells, wells in tank command area and tubewell-irrigated farms, respectively. Area under high water intensive crops namely, paddy and sugarcane declined almost in all the optimal crop plans. Area under low water intensive crops (groundnut, gingelly and tapioca) showed an increasing trend in all optimal crop plans. The net income of the sample farms increased marginally or considerably in the optimal crop plans of both the critical and over-exploited groundwater regime sample farms and semi-critical and the safe groundwater regime sample farms.

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Introduction

Groundwater is a critically important resource. It is generally taken for granted that the groundwater drawn from the wells is omnipresent and will always be available. However, the groundwater resources can also get exhausted if not managed properly over space and time. The groundwater resources lying close to the urban areas are facing the pressure of exploding population and industrialization. Consequently, over-draft of groundwater in many parts of the country is pushing the water-table downward. Falling water tables and depletion of economically accessible groundwater resources would have major social and economic problematic consequences. The estimated irrigation potential in the Tamil Nadu state from the surface and groundwater resources is estimated as 56.47 lakh ha (31.47 lakh hectares from the groundwater sources and 25 lakh hectares from surface water resources). According to the Central Groundwater Authority, India, the following districts (in pockets) of Tamil Nadu have shown a fall in the groundwater level of more than 4 metres per annum as per the long-term water level trends during the post-monsoon period (1981-2000). In Tamil Nadu, 52 blocks had over-exploited (>100% utilization) the groundwater, and 37 blocks had come under dark area (85-100% of groundwater development). Eighty-six blocks had utilized 65-85 per cent of their groundwater potential. The remaining 210 blocks were classified as white area with less than 65 per cent of groundwater development. This would mean that 45 per cent of the total area of the state had already over-exploited the groundwater potential.

Perambalur District

Perambalur district mainly depends on groundwater for its irrigation. In the district, 67 per cent of the area was irrigated by open-wells and tube-wells. The district comprises ten blocks of which (in 1992), Perambalur and Veppanthattai blocks came under the grey category (65-85%) and the remaining eight blocks under white category (< 65%) of groundwater development (www.perambalur.nic.in). However, in about six years time, according to the State Groundwater Development Authority, the blocks of Perambalur and Veppanthattai became over-exploited (> 100%) and the Veppur block was classified as semi-critical (70-90%) in terms of groundwater development. However, the area under paddy and sugarcane was 51,931 ha and 13,045 ha, respectively, which accounted for 23 per cent and 6 per cent of the gross cropped area. It was clearly higher than the area under paddy (47,575 ha) and sugarcane (11,733 ha) in the district during the year 1996-97. This showed that the farmers were unconcerned about the falling water-table in the district. Under this bakcdrop, the present study

was taken up with the overall objective of evolving optimal crop plans to sustain the underground irrigation water sources.

Sampling Design and Methodology

The Perambalur district of Tamil Nadu was purposively selected for the study on the basis of a comparatively high percentage of area irrigated by wells, accounting for 67.22 per cent of the total area irrigated. The district had ten blocks, and for the present study, four blocks, two each from the over-exploited and critical groundwater regime (Perambalur and Veppanthattai) and the semi-critical and safe groundwater regime (Alathur and Veppur) were selected in the first stage. One village was selected randomly from each block in the second stage and 30 respondents were randomly selected from each village in the third stage of sampling. The primary data were collected through personal contact with the respondents using a pre-tested questionnaire. The data constituted information on landholdings, irrigation particulars, well particulars, cropping pattern, and costs and returns of major crops. The primary data collected from 120 farmers each were drawn in three irrigation sources: (a) Open ordinary wells, (b) Wells in the tank command area, and (c) Tube-wells and open-cum-tube wells in critical and over-exploited groundwater regime and in semi-critical and safe groundwater regime, respectively.

Linear Programming

The objective function was to maximize aggregate net income from crops grown in the farm. The mathematical model was of the following form:

Maximize $Z = \sum_{j=1}^{n} C_j X_j$

subject to

$\sum_{j=1}^{n} x_j \leq l_i$

i = 1,2

1= First period from June to December

2= Second period from January to May

$\sum_{i=1}^{n} a_{mj} x_i \leq w_m$

m = 1,2, ….., 5

1 = April

2 = May

3 = June

4 = July

5 = August

$\sum_{j=1}^{n} a_{jk} x_j \leq k$

Capital limit in rupees

where,

Z = Aggregate net income from the crops (Rs)

C_j = Net return over variable costs per unit of the jth activity (Rs)

X_j = Area under the jth crop or real activity

l_1 = Land available for cultivation in period-1 from June-December (ha)

l_2 = Land available for cultivation in period-2 from January-May (ha)

w_m = Water availability in the mth month (hours)

k = Amount of working capital availability

a_{mj} = Amount of water required for the jth crop in mth month

a_{jk} = Average amount of capital required for the jth crop.

Selection of the Typical Farm

The averages of the cropping intensity, size of holding, utilization of irrigation water, labour utilization, cash expenditure and net returns of all the farms in a particular situation were calculated and a farm which was very close to this average was taken as the typical farm for that situation (Selvarajan, 1976). Thus, six typical farms were selected, one each for open well, wells in tank command area and tubewell-irrigated farms in the critical and over-exploited groundwater regime and also for the semi-critical and safe groundwater regime.

Input Coefficients

For programming under actual farm situation, the input coefficients included were the averages of all the farms surveyed in the region. These input coefficients were considered for enterprises that were being adopted currently in the nodal farm.

Resource Constraints

The core of linear programming problem was the fact that the resources were limited. In the area under study, the most restricting resources identified primarily were irrigation water, land availability during the cultivating seasonss and capital.

Land Restrictions

Land as a resource in a particular farm could not be increased by way of purchase or lease at least in a short period. Hence, land was one of the most limiting factors to be considered in the formulation of the problem. Land was classified in the present study into two categories based on the season of cropping. Since the ploughing for the first season crop would start from June itself, the farmers were going for paddy or onion. The Samba crop was raised from August-September onwards. The first period was taken from June to December and the second from December-January to end of May. The equality constraints were based on the fact that the area allocated to sugarcane or tapioca would not be available for other crops.

Capital Restrictions

Capital as a restriction has been studied by a number of production economists. The capital requirements of farmers were met through the credits facilitated by various institutions, borrowings from neighbours, and from own resources. In the study area, the farmers were growing high-value crops like onion and sugarcane, hence capital was found to be a limiting factor.

Irrigation Water Restrictions

Irrigation was identified as the crucial factor for cultivation of crops in the study region. In order to decide the critical periods for irrigation applications, monthly requirements of irrigation water for different crops were estimated in terms of hours of pumping for irrigation to these crops. Narayanamoorthy (2003) had measured water consumption in terms of horse power hours of irrigation. From the normal rainfall data of the study area and the monthly availability of under groundwater for irrigation, the months of April, May, June, July and August were identified as critical periods. The reasoning behind the identification of this constraint was to reduce the use of scarce undergroundwater resources during the critical period when recharge would be less or nil, as compared to the actual use or requirement. The assumptions underlying this constraint were that water demand should (i) match with water availability, and (ii) be decided on the basis of relative returns from crops using water, especially during the critical period of undergroundwater availability.

Availability of Resources and Inputs

Having estimated the resource requirements and identified the restricting resources, it was essential to assess the availability of resources. For

compiling the resource availability, the resources available in the selected farms were estimated from the survey data. The irrigation potential of the wells was estimated as the average pumping hours possible in the farm during each of the twelve months of the year.

Linear Programming Results

Optimal Crop Plans derived for Critical and Over-exploited Groundwater Regimes

Open Ordinary Well-irrigated Farm

The analysis of the cropping pattern in the nodal farm revealed that the existing plan consisted of six crops, viz. paddy-1, paddy-*samba*, onion, sugarcane, groundnut and gingelly. In the existing plan, paddy was cultivated on 1.2 ha of land during the two seasons, namely *kuruvai* starting from June, and *samba* starting from August. Sugarcane, onion and groundnut were cultivated in 0.4 ha each, and gingelly in 0.2 ha. The critical period for irrigation water was April - August. The net income was estimated to be Rs 45,436. The cropping intensity was 162.5 per cent (Table 1). In the optimal plan, the *kuruvai* season paddy (0.40 ha) requiring water during the critical period of groundwater availability was removed. The area under paddy-2 declined marginally from 0.80 ha to 0.73 ha and that under onion from 0.40 ha to 0.27 ha. However, the area under sugarcane increased from 0.40 ha to 0.60 ha and that of groundnut from 0.40 ha to 0.73 ha. As in the case of paddy-1, gingelly was also removed from the optimal plan. Even though the cropping intensity declined from 162.5 to 145.83 per cent in the optimal plan, the net income marginally increased by Rs 209.00. The important outcome was that the use of groundwater during the critical period alone declined by 24.3 hours of pumping, which went a long way in optimizing water-use during the critical period. The capital requirement declined marginally by Rs 1125.00 and the gross cropped area declined by 0.27 ha, which implied relatively less pressure on land that indicated the sign of bringing in sustainability of the productive capacity of the land.

Tank Command Well-irrigated Farm

In the tank command well-irrigated farm, the selected four crops, namely paddy, sugarcane, groundnut, and gingelly were grown in 0.80, 0.40, 0.60 and 0.20 ha, respectively. The cropping intensity was 166.67 per cent. The net income realized was Rs 30,820 in the existing plan (Table 2). In the optimal plan, paddy area declined from 0.80 to 0.70 ha; sugarcane area

Table 1. Optimal crop plan for open ordinary well farm in critical and over - exploited groundwater regimes

Particulars	Season	Existing area (ha)	Optimal crop area (ha)	Per cent change
Paddy-1 (ha)	June last week to Sep end	0.40 (15.38)	0.00 (0.00)	-0.40
Paddy-*samba* (ha)	Aug-Sep to Dec end	0.80 (30.77)	0.73 (31.43)	0.73
Paddy total (ha)		1.20 (46.15)	0.73 (31.43)	-0.47 (-64.38)
Onion (ha)	Oct first week to Dec end	0.40 (15.38)	0.27 (11.43)	-0.13 (-32.50)
Sugarcane (ha)	Dec-Jan	0.40 (15.38)	0.60 (25.71)	0.20 (+50.00)
Groundnut (ha)	Jan-Feb	0.40 (15.38)	0.73 (31.43)	0.33 (+57.50)
Gingelly (ha)	Jan-Feb	0.20 (7.69)	0.00 (0.00)	-0.20
High water-intensive crops (Paddy, sugarcane, onion) (ha)		2.00 (76.91)	1.60 (68.57)	-0.40 (-8.34)
Low water-intensive crops (Groundnut, gingelly) (ha)		0.60 (23.09)	0.73 (31.43)	0.13 (8.34)
Net income (Rs)		45,436	45,645	209.00
Water used in critical period (hrs)		110.2	85.9	-24.3
Capital used (Rs)		62,248	61,123	-1,125
Gross area (ha)		2.60	2.33	-0.27
Net area (ha)		1.60	1.60	
Cropping intensity (%)		162.50	145.83	

Note: Figures within the parentheses indicate percentages to the gross cropped area
+ Increase; - Decrease

increased from 0.40 ha to 0.50 ha, groundnut area declined from 0.60 ha to 0.46 ha and gingelly area increased marginally from 0.20 ha to 0.24 ha. Even though the cropping intensity had declined from 166.67 to 158.33 per cent in the optimal plan, the net income had increased marginally by Rs 388.00. During the critical period, use of irrigation water had declined by 4.54 pumping hours. The total pumping hours were relatively low at 103.10 in the current plan as compared to open-well farms with 110.20 hours. The decline in the gross cropped area to 1.90 ha as against 2.00 ha in the existing plan indicated a marginal reduction in the pressure on land.

Table 2. Optimal crop plan for wells in tank command area farm in critical and over-exploited groundwater regimes

Particulars	Season	Existing area (ha)	Optimal crop area (ha)	Per cent change
Paddy-*samba* (ha)	Aug-Sep to Dec	0.80	0.70	-0.10
		(40.00)	(36.84)	(-12.50)
Sugarcane (ha)	Dec-Jan	0.40	0.50	0.10
		(20.00)	(26.32)	(+25.00)
Groundnut (ha)	Jan-Feb	0.60	0.46	-0.14
		(30.00)	(24.30)	(-23.33)
Gingelly (ha)	Jan-Feb	0.20	0.24	0.04
		(10.00)	(12.54)	(+20.60)
High water-intensive crops (Paddy, sugarcane) (ha)		1.20 (60.00)	1.20 (63.16)	0.00 (-3.16)
Low water-intensive crops (Groundnut, gingelly) (ha)		0.80 (40.00)	0.70 (36.84)	-0.10 (3.16)
Net income (Rs)		30,820	31,280	388.00
Water used in critical period (hours)		103.10	98.56	-4.54
Capital used (Rs)		42,108	42,209	101.00
Gross area (ha)		2.00	1.90	
Net area (ha)		1.20	1.20	
Cropping intensity (%)		166.67	158.33	

Note: Figures within the parentheses indicate percentages to the gross cropped area
+ Increase; - Decrease

Tubewell-irrigated Farm

Paddy-1, paddy-*samba* and paddy-2 were grown in 0.40 ha, 0.80 ha, and 0.40 ha, respectively in the existing situation in the tube-well farm of critical and over-exploited groundwater regimes. Sugarcane, tapioca, groundnut and gingelly were cultivated in 0.80 ha, 0.40 ha, 0.40 ha and 0.20 ha, respectively. The cropping intensity was 141.67 per cent (Table 3). In the optimal plan, both paddy-1 and paddy-2 were removed. The area under *samba*-paddy increased from 0.80 ha to 1.20 ha, sugarcane area came down from 0.80 ha to 0.64 ha, groundnut area increased from 0.40 ha to 1.20 ha and tapioca area increased from 0.40 ha to 0.56 ha. The results showed that the area under high water-intensive crops, namely paddy, sugarcane and onion, decreased from 2.40 ha to 1.84 ha, whereas the area under low water-intensive crops like tapioca and groundnut increased from 1.00 ha to 1.76 ha in the optimal plan. Use of irrigation water during the

Table 3. Optimal crop plan for tube-well farm in critical and over-exploited groundwater regimes

Particulars	Season	Existing area (ha)	Optimal crop area (ha)	Per cent change
Paddy-1 (ha)	June last week to Sep end	0.40 (11.76)	0.00 (0.00)	-0.40
Paddy-*Samba* (ha)	Aug-Sep to Dec end	0.80 (23.54)	1.20 (33.33)	0.40
Paddy-2 (ha)	Oct to Dec-Jan	0.40 (11.76)	0.00 (0.00)	-0.40
Paddy-total (ha)		1.60 (47.05)	1.20 (33.33)	0.40 (-25.00)
Sugarcane (ha)	Dec-Jan	0.80 (23.54)	0.64 (17.72)	-0.16 (-25.00)
Tapioca (ha)	Jan-Feb	0.40 (11.76)	0.56 (15.62)	0.16 (+40.00)
Groundnut (ha)	Jan-Feb	0.40 (11.76)	1.20 (33.33)	0.80 (+200.00)
Gingelly (ha)	Jan-Feb	0.20 (5.88)	0.00 (0.00)	-0.20
High water-intensive crops (Paddy, sugarcane, onion) (ha)		2.40 (70.60)	1.84 (51.05)	-0.56 (-19.55)
Low water-intensive crops (ha) (Groundnut, gingelly, tapioca)		1.00 (29.40)	1.76 (48.95)	0.76 (19.55)
Net income (Rs)		58,744	61,226	2,482
Water used in critical period (hours)		193.80	142.09	-51.71
Capital used (Rs)		78,380	80,000	1,620
Gross area (ha)		3.40	3.60	
Net area (ha)		2.40	2.40	
Cropping intensity (%)		141.67	150.00	

Note: Figures within the parentheses indicate percentages to the gross cropped area
+ Increase; - Decrease

critical period came down drastically by 51.71 pumping hours. This was of considerable importance since tube-well irrigation intensified groundwater exploitation. The net income increased by Rs 2,482 and the cropping intensity increased to 150.00 per cent in the optimal plan mainly because of considerable increase in the area under low water-intensive crops.

Optimal Crop Plans Derived for Semi-Critical and Safe Groundwater Regimes

Open/Ordinary Well-irrigated Farm

In the open well-irrigated farm, five crops, namely onion, paddy-*samba*, paddy-2, sugarcane and groundnut were grown in 0.40 ha each. The cropping intensity was 166.67 per cent in the existing plan. The net income realized was Rs 37,656. Onion was cultivated fully during the critical period from June to August. Paddy was grown first as *samba* crop and again after harvesting of onion (Table 4). In the optimal plan, the area under onion

Table 4. Optimal crop plan for open/ordinary well farm in semi-critical and safe groundwater regimes

Particulars	Season	Existing area (ha)	Optimal crop area (ha)	Per cent change
Onion (ha)	June to Aug last week	0.40 (20.00)	0.37 (19.52)	-0.03
Paddy-*samba* (ha)	Aug-Sep to Dec	0.40 (20.00)	0.33 (17.32)	-0.07
Paddy-2 (ha)	Oct to Dec-Jan	0.40 (20.00)	0.00 (0.00)	-0.40
Paddy-total (ha)		0.80 (40.00)	0.33 (17.32)	0.47 (-58.75)
Sugarcane (ha)	Dec-Jan	0.40 (20.00)	0.50 (26.32)	0.10 (+25.00)
Groundnut (ha)	Jan-Feb	0.40 (20.00)	0.70 (36.84)	0.30 (+75.00)
High water-intensive crops (Paddy, sugarcane, onion) (ha)		1.60 (80.00)	1.20 (63.16)	-0.40 (-16.84)
Low water-intensive crops (Groundnut, gingelly) (ha)		0.40 (20.00)	0.70 (36.84)	0.30 (16.84)
Net income (Rs)		37,656	38,354	698.00
Water used in Critical period (hours)		97.60	92.99	-4.61
Capital used (Rs)		52,872	52,459	-413.00
Gross area (ha)		2.00	1.90	
Net area (ha)		1.20	1.20	
Cropping intensity (%)		166.67	158.33	

Note: Figures within the parentheses indicate percentages to the gross cropped area.
+ Increase; - Decrease

declined marginally to 0.37 ha and paddy-2 was totally removed. Thus, the total paddy area had declined from 0.80 ha to 0.33 ha. On the other hand, area under sugarcane had increased from 0.40 ha to 0.50 ha and under groundnut from 0.40 ha to 0.70 ha. The net income increased marginally by Rs 698. The critical period irrigation water-use was reduced by 4.61 pumping hours even though the water-use in the existing plan was also lower at 97.60 pumping hours during that period. The cropping intensity had declined from 166.67 to 158.33 per cent. The area under high water-intensive crops like paddy, sugarcane and onion came down in the optimal plan from 1.60 ha to 1.20 ha. The area under low water-intensive crop, groundnut, had increased by 0.30 ha. There was a reduction of 0.10 ha in gross cropped area in the optimal plan. The cropping intensity also declined, even through the net income had increased.

Tank Command Well-irrigated Farm

In the tank command well-irrigated farm, five crops, namely onion, paddy-*samba*, paddy-2, sugarcane and groundnut were cultivated in the existing plan in 0.20 ha, 0.40 ha, 0.40 ha, 0.40 ha and 0.40 ha, respectively. Paddy was grown in *samba* and *thaladi* seasons. Onion was cultivated fully during the critical months of irrigation water availability. The cropping intensity was 160.00 per cent. The net income was estimated to be Rs 30,558 (Table 5). The net income had increased by Rs 281 in the optimal plan. The total paddy area declined to 0.39 ha and onion area declined marginally to 0.15 ha. Sugarcane and groundnut areas increased to 0.46 and 0.54 ha, respectively from the existing 0.40 ha each. The overall area under high water-intensive crops, namely onion, paddy, and sugarcane, had reduced from 1.20 ha to 1.00 ha. The area under low water-intensive crop, groundnut, had increased from 0.40 ha to 0.54 ha. The irrigation water-use during the critical period came down by 3.99 pumping hours in the optimal plan (from 79.59 to 75.60 pupming hours). Even though the gross cropped area and the cropping intensity had declined to 1.54 ha and 154.00 per cent, respectively, the net income realized had increased marginally by Rs 281.00.

Tubewell and Open-cum-tubewell-irrigated Farm

In the tubewell-irrigated farm, paddy, sugarcane, groundnut and gingelly were cultivated in 0.80 ha, 1.20 ha, 0.40 ha and 0.40 ha, respectively. Paddy was grown in the *samba* season. The cropping intensity was 140.00 per cent, only as sugarcane had occupied 42.86 per cent of the gross cropped area. The net income was estimated as Rs 53, 712 (Table 6). In the optimal plan, the area under *samba*-paddy increased marginally from 0.80 ha to

Table 5. Optimal crop plan for wells in tank command area farm in semi- critical and safe groundwater regimes

Particulars	Season	Existing area (ha)	Optimal crop area (ha)	Per cent change
Onion (ha)	June to Aug last week	0.20 (12.50)	0.15 (9.81)	-0.05
Paddy -*samba* (ha)	Aug-Sep to Dec	0.40 (25.00)	0.39 (25.25)	-0.01
Paddy-2 (ha)	Oct to Dec-Jan	0.20 (12.50)	0.00 (0.00)	-0.20
Paddy-total (ha)		0.60 (37.50)	0.39 (25.25)	-0.21 (-35.00)
Sugarcane (ha)	Dec-Jan	0.40 (25.00)	0.46 (29.87)	0.06 (+15.00)
Groundnut (ha)	Jan-Feb	0.40 (25.00)	0.54 (35.07)	0.14 (+35.00)
High water-intensive crops (Paddy, sugarcane, onion) (ha)		1.20 (75.00)	1.00 (64.93)	-0.20 (-10.07)
Low water-intensive crops (Groundnut, gingelly) (ha)		0.40 (25.00)	0.54 (35.07)	0.14 (10.07)
Net income (Rs)		30,558	30,839	281.00
Water used in critical period (hours)		79.59	75.60	-3.99
Capital used (Rs)		56,868	58,716	1,848
Gross area (ha)		1.60	1.54	
Net area (ha)		1.00	1.00	
Cropping intensity (%)		160.00	154.00	

Note: Figures within the parentheses indicate percentages to the gross cropped area
+ Increase; - Decrease

0.89 ha, sugarcane area declined marginally from 1.20 ha to 1.11 ha, groundnut area increased to 0.71 ha, and gingelly area came down to 0.18 ha. The critical period irrigation water-use had declined by 4.73 pumping hours. The gross cropped area increased from 2.80 ha to 2.89 ha. The cropping intensity also increased to 144.50 per cent, while the area under high water-intensive crops remained unchanged. However, the area under low water-intensive crops increased from 0.80 ha to 0.89 ha. The net income had increased by Rs 2,019, even though the area under high water-consuming crops remained unaltered in the optimal plan.

Table 6. Optimal crop plan for tubewell and open-cum-tubewell farm in semi-critical and safe groundwater regimes

Particulars	Season	Existing area (ha)	Optimal crop area (ha)	Per cent change
Paddy-*Samba* (ha)	Aug-Sep to Dec	0.80 (28.56)	0.89 (30.80)	0.09 (+11.25)
Sugarcane (ha)	Dec-Jan	1.20 (42.86)	1.11 (38.41)	-0.09 (-7.50)
Groundnut (ha)	Jan-Feb	0.40 (14.29)	0.71 (24.61)	0.31 (+77.50)
Gingelly (ha)	Jan-Feb	0.40 (14.29)	0.18 (6.18)	-0.22 (-55.00)
High water-intensive crops (Paddy, sugarcane, onion) (ha)		2.00 (71.43)	2.00 (69.21)	0.00 (-2.22)
Low water-intensive crops (Groundnut, gingelly) (ha)		0.80 (28.57)	0.89 (30.79)	0.19 (2.22)
Net income (Rs)		53,712	55,652	1,940
Water used in critical period (hours)		164.80	160.07	-4.73
Capital used (Rs)		71,604	73,623	2,019
Gross area (ha)		2.80	2.89	
Net area (ha)		2.00	2.00	
Cropping intensity (%)		140.00	144.50	

Note: Figures within the parentheses indicate percentages to the gross cropped area.
+ Increase; - Decrease

Conclusions

The results of the optimal crop plans have shown that the irrigation water-use during the critical period could be reduced by 24.30, 4.54 and 51.71 pumping hours in ordinary wells, wells in tank command area and tubewell-irrigated farms, respectively in the critical and over-exploited groundwater regime sample farms. In the semi-critical and safe groundwater regime sample farms, the optimal crop plan has revealed that the irrigation water-use during the critical period could be reduced by 4.61, 3.99 and 4.73 pumping hours in ordinary wells, wells in tank command area and tube-well irrigated farms, respectively. The area under high water-intensive crops, namely, paddy, sugarcane and onion has declined almost in all the optimal crop plans derived for critical and over-exploited groundwater regime sample farms, and semi-critical and safe groundwater regime sample farms. The area under low water-intensive crops (groundnut, gingelly and tapioca) has

shown an increasing trend in all optimal crop plans. The net income of the sample farms has increased marginally or considerably in the optimal crop plans of both critical and over-exploited groundwater regime sample farms, and semi-critical and safe groundwater regime sample farms.

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