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Impact of Drip Irrigation on Farming System: Evidence from Southern India

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Abstract

The micro irrigation in general and drip irrigation in particular has received considerable attention from policy makers, researchers, economists etc. for its perceived ability to contribute significantly to groundwater resources development, agricultural productivity, economic growth, and environmental sustainability. In this paper, the impact of drip irrigation has been studied on farming system in terms of cropping pattern, resources use and yield. The drip method of irrigation has been found to have a significant impact on resources saving, cost of cultivation, yield of crops and farm profitability. Hence, the policy should be focused on promotion of drip irrigation in those regions where scarcity of water and labour is alarming and where shift towards wider-spaced crops is taking place.

Introduction

Developing infrastructure for the water resources and their management have been the common policy agenda in many developing economies, particularly in the arid and semi-arid tropical countries like India. A study by the International Water Management Institute (IWMI) has shown that around 50 per cent of the increase in demand for water by the year 2025 can be met by increasing the effectiveness of irrigation (Seckler *et al.*, 1998).

The review of past studies lucidly shows that the solution to the problem of growing groundwater scarcity and persistent groundwater resource degradation across regions is two-fold. The first is the supply side management practices like watershed development, water resources development through major, medium and minor irrigation projects, etc. The second is through the demand management by efficient use of the available water both in the short-run and long-run perspectives. This includes drip irrigation and other improved water management practices. Recognising the importance of sustainable water-use efficiency in agriculture, a number of demand management strategies (like water pricing, water users association, turnover system, etc.) have been introduced since the late-1970s to increase the water-use efficiency, especially in the use of surface irrigation water. One of the demand management mechanisms is the adoption of micro irrigation such as drip and sprinkler methods of irrigation. Evidences show that the water-use efficiency increases up to 100 per cent in a properly designed and managed drip irrigation system (INCID, 1994; Sivanappan, 1994). Drip method of irrigation helps to reduce the over-exploitation of groundwater that partly occurs because of inefficient use of water under surface method of irrigation. Environmental problems associated with the surface method of irrigation like waterlogging and salinity are also completely absent under drip method of irrigation (Narayanamoorthy, 1997). Drip method helps in achieving saving in irrigation water, increased water-use efficiency, decreased tillage requirement, higher quality products, increased crop yields and higher fertilizer-use efficiency (Qureshi *et al.*, 2001; Sivanappan, 2002; Namara *et al.*, 2005).

Though the potential benefits generated by the drip irrigation methods are apparent, the adoption of drip

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irrigation is yet to be widely promoted across regions, states and elsewhere. It is found that the most ideal policy environment for promotion of micro irrigation technologies in the well-irrigated areas would be pro-rata pricing of electricity, which would create direct incentive for efficient water use (Kumar, 2005). Adoption of micro irrigation systems is likely to pick up fast in the arid and semi arid, well-irrigated areas, where farmers have independent irrigation sources, and where groundwater is scarce. Further, large size of farm and individual plots, and a cropping system dominated by widely-spaced row crops, which are also high-valued, would provide the ideal environment for the same (Kumar *et al.*, 2005). Evidences show that many researchers have attempted to study the impact of drip irrigation (Narayanamoorthy, 2005; Qureshi *et al.*, 2001; Namara *et al.*, 2005; Kulecho and Weatherhead, 2005; Narayanamoorthy, 2003; Dhawan, 2002; Verma *et al.*, 2004; Magar *et al.*, 1988; Cuykendall *et al.*, 1999) and have found that drip irrigation produces the desired positive impacts. It is evidenced that the drip irrigation technology is technically feasible, particularly when the farmers depend on groundwater sources (Dhawan, 2000). Still, the studies on impacts of drip irrigation on the farming system as a whole are scanty and yet to be explored much.

In this context, the drip irrigation has received much attention from policy makers and others for its perceived ability to contribute significantly to groundwater resources development, agricultural productivity, economic growth, and environmental sustainability. Yet in many parts of the country and elsewhere, these have yet to be adopted widely. Keeping these issues in view, the present paper has addressed the following important issues: (i) what changes the drip irrigation brings to the farming system?, (ii) whether the adoption of drip irrigation is motivated by the cropping pattern or the cropping pattern is followed by drip adoption? and (iii) what policy action must be taken at different levels to speed up the adoption of drip irrigation?

Methodology

Sampling Framework

The study was conducted in the Coimbatore district of Tamil Nadu state where groundwater resource degradation is alarming. Two blocks were selected so as to represent drip adoption and control. From the selected blocks, two revenue villages were selected purposively where the adoption of drip irrigation is widespread. Farm households in the selected villages constituted the sample units. To examine the adoption and impact of drip irrigation on resource use, agricultural production and farm income, 25 drip-adopting farmers were selected in each village and correspondingly 25 non-drip adopters were selected in control villages. To select the drip adopters, the list of farmers from the Department of Agricultural Engineering was collected. Also, we enumerated the list of farmers adopting drip irrigation after discussions with the villagers and private firms dealing drip irrigation systems. Thus, a sample of 100 farmers was studied.

The Data

For the purpose of the study, both secondary and primary information was collected from different sources. The secondary information included trend in rainfall, growth in the number of wells, number of wells functioning and wells defunct, cropping pattern, crop yields, occupational structure and area irrigated. The general particulars of the area were collected from the Assistant Director of Statistics and Assistant Director of Agriculture of the respective regions. Interview schedules were formulated and pre-tested. The needed information from the respondent group was gathered personally administering the interview schedule. The primary information collected from the farm households included details on well investment, groundwater use, extraction and management, crop production including input use and output realised, farm income, adoption of drip irrigation, and investment on drip irrigation. This also included asset position, education and other socio-economic condtions.

Markov Chain Analysis

Our objective here was to study the changes that have occurred in the farming system, particularly through cropping pattern as a result of adoption of drip irrigation. In order to examine the changes in the cropping pattern, Markov chain analysis was performed.

Markov chain models are concerned with the problems of movement, both in terms of movement from one location to another and in terms of movement from one "state" to another. These models are used for describing and analysing the nature of changes generated by the movement of such variables, in some cases these models may also be used to forecast future changes (Collins, 1975).

The changing cropping pattern was worked out assuming that it follows a first order Markov chain (Lee *et al.*, 1965), as explained below.

A first order Markov chain is characterized by the transition probability matrix, given by expression (1):

$$P = \begin{bmatrix} p_{11} & p_{12} & \cdots & p_{1n} \\ p_{21} & p_{22} \cdots & p_{2n} \\ \cdots & & \cdots \\ p_{n1} & p_{n2} & \cdots p_{nn} \end{bmatrix} \qquad \ldots(1)$$

where, p_{ij} is the probability that an area under the classification 'i' during the current year changes into the classification 'j' next year and 'n' is the number of states. That is,

$$pij = Pr\{X(t+1) = j \,/\, X(t) = i\} \qquad \ldots(2)$$

where, $X(t)$ = State of the system at the year 't'. It is clear that

$$p_{ij} \geq o, \qquad i,j = 1,2,\ldots,n \quad \text{and}$$

$$\sum_{j=1}^{j=n} p_{ij} = 1, \qquad i = 1,2,\ldots,n \qquad \ldots(3)$$

The transition probability matrix for the study was 9 × 9 matrix resulting in 81 unknown probabilities p_{ij}, i, j = 1,2…,9, which were estimated using farm level data.

In this paper, the structural change in cropping pattern after introduction of drip irrigation system was examined by using the Markov chain approach. The estimation of the transitional probability matrix (P) was central to this analysis. The element P_{ij} of the matrix indicated the probability that the area would switch from the i^{th} crop to j^{th} crop over a period of time, i.e. after the introduction of drip irrigation system. The diagonal elements P_{ij} indicated the probability that the area share of a crop would be retained in the successive time periods.

The Study Area

Drip Irrigation in Tamil Nadu

Tamil Nadu state stands seventh in the country in terms of area under micro irrigation. During 2008, a total area of 158521 ha was practised under micro irrigation in the Tamil Nadu state. Of the total area under micro irrigation, the drip accounted for 82.85 per cent (131335 ha) and sprinkler for 17.15 per cent (27186 ha). At the national level, the area under drip irrigation was 36.82 per cent and under sprinkler was 63.18 per cent (Figure 1). It is clear that the drip method of irrigation is more popular among the farmers in Tamil Nadu when compared to sprinkler method of irrigation. It is seen that the Tamil Nadu state has only 9.2 per of the total drip area in the country where as the sprinkler irrigation accounts for only 1.1 per cent of total area in the country. The area under micro irrigation accounts 4.1 per cent of the total area under irrigation in the country.

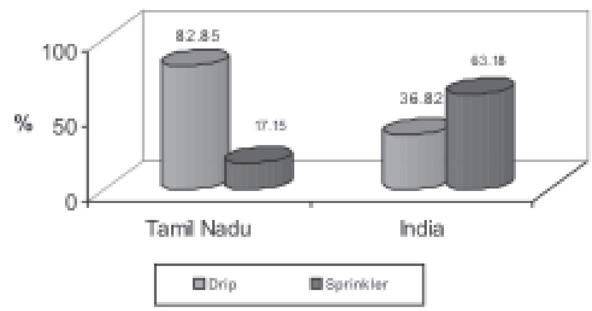

Figure 1. Proportion of area under different micro irrigation systems in India and Tamil Nadu

The area under micro irrigation is very low in Tamil Nadu when compared to the national level area. The net sown area of the state is 51.26 lakh ha, whereas the gross cropped area is 58.42 lakh ha. The area under micro irrigation accounts for only 3.1 per cent of the net sown area of the state, whereas it accounts for 5.49 per cent of the net irrigated area and 4.79 per cent of the gross irrigated area. Thus, there is a huge potential to increase the area under micro irrigation in the state.

In the study area, i.e. the Coimbatore district of Tamil Nadu state, agriculture depends largely on minor irrigation projects and other sources such as wells, rainfed tanks, etc. The chief source of irrigation in the district is through wells. The average well-failure rate is 47 per cent for open-wells and 9 per cent for bore-wells (Palanismai *et al.*, 2008). There are six different soil types, viz. red calcareous soil, black soil, red non-calcareous soil, alluvial and colluvial soil, brown soil and forest soil. The mean annual rainfall for the 45 years (between 1961 and 2005) is worked out to be 687.1 mm and the coefficient of variation is worked out to be 28.21 per cent. The distribution of rainfall across seasons indicates that the mean rainfall ranged from 16 mm during winter to 348 mm during north-east monsoons. The groundwater potential as on January 2003 indicated that the total groundwater recharge was 880.97 million cubic metre (MCM), net groundwater availability (90 % of total groundwater recharge) was 792.87 MCM, domestic and industrial draft was 40.57 MCM, irrigation draft was 779.13 MCM and the stage of groundwater development was 103 per cent.

The level of groundwater development exceeds 100 per cent of the utilisable groundwater recharge in eleven blocks, between 90 and 100 per cent in four blocks and between 70 and 90 per cent in another four blocks. The stages of groundwater development in the study blocks, viz. Thondamuthur and Annur blocks was 169 per cent and 173 per cent, respectively indicating the problem of groundwater in the region. Increasing private investment on wells is visualized over the years as groundwater irrigation assumes importance. Farmers in this district rely heavily on groundwater for irrigation. The source-wise area irrigated indicates that the groundwater accounts for 88.7 per cent and 52 per cent of the total area irrigated in the Thondamuthur and Annur blocks, respectively. The increasing trend in groundwater irrigation further confirms a heavy dependence on it for irrigation.

Results and Discussion

Farm Level Impacts of Drip Irrigation

Here our aim was to observe the significant changes in landholdings, cropped area, and irrigated area due to the introduction of drip irrigation. For this purpose, the drip-adopters were compared with control households. The average size of holding among the drip-adopters was significantly large as compared to control villages. Since drip method of irrigation involves huge initial investment, large farmers adopt it widely as compared to small and marginal farmers (Table 1).

The details regarding before drip adoption was collected based on the recall basis. For control villages, the reference period for the pre-adoption was considered to be 10 years before, i.e. 1995

It is argued that drip irrigation increases cropped area and area under irrigation as it is a viable water-saving technology. Our study confirms the earlier findings that the drip irrigation technology increases the net sown area and net irrigated area and thereby helps in achieving higher cropping intensity and irrigation intensity. For instance, in the drip villages, the net sown area has increased from 4.51ha to 5.31ha, whereas the gross cropped area has increased from 4.77 ha to 6.36 ha. A similar positive trend was seen in the net irrigated area and gross irrigated area. During the

Table 1. General characteristics of sample households in Tamil Nadu

Crops	Drip villages		Control villages	
	Before	After	Before	After
Number of workers in the household (No.)	2.7	2.7	1.92	1.92
Farm size (ha)	5.52	5.41	2.23	2.28
Net sown area (ha)	4.51	5.31	1.41	1.35
Gross cropped area (ha)	4.77	6.36	1.46	1.39
Cropping intensity (%)[a]	105.57	124.34	103.54	102.96
Net irrigated area (ha)	3.65	4.97	1.27	1.22
Gross irrigated area (ha)	3.84	6.26	1.28	1.22
Irrigation intensity (%)[b]	104.88	130.16	100.18	100.00
Percentage of area irrigated by wells to the total cropped area (%)	82.0	98.03	94.65	94.26
Percentage of area irrigated under drip to gross cropped area (%)	67.14			
Percentage of area irrigated under drip to gross irrigated area (%)	68.57			

Source: Field survey during 2007-2008

Notes : ***, ** and * indicate values are significantly different at 1 per cent, 5 per cent and 10 per cent levels from the corresponding values of control village

[a] Cropping intensity is defined as the ratio of gross cropped area to net sown area and is expressed as a percentage

[b] Irrigation intensity is the ratio of gross irrigated area to net irrigated area and is expressed as a percentage

survey, it was found that drip irrigation technology has resulted in significant impacts. Being an efficient water-saving technology, it has helped in expanding the irrigated area and saving of water.

The percentage of area irrigated by wells to the total cropped area has significantly increased in the drip villages among drip adopters. It is evidenced that the percentage of area irrigated by wells to gross cropped area has increased from 82.0 per cent to 98.03 per cent due to the drip intervention. It is lucid from the analysis that drip irrigation technology has resulted significant positive impacts in the farming system.

Cropping Pattern

An attempt was made to find *whether drip irrigation had induced a certain new cropping system or the crops had followed drip technology as a response to the growing water scarcity?* The cropping pattern, i.e. proportion of area under different crops, is a good indicator of the development of resource endowments and agricultural production. It is expected that drip method of irrigation helps in the development of water resource potential and also helps the farmers to get more crop and income per drop of water.

The longitudinal analysis of cropping pattern across farm households and villages has revealed that the adoption of drip irrigation is motivated by many factors. The two major constraints limiting agricultural production are: human labour and water scarcity. These two factors had compelled the farmers to alter their cropping pattern towards less labour and water-intensive crops. The resource-poor farmers were going in for rainfed crops like sorghum, maize, etc. However, the big farmers who had access to capital, were adopting various water management and coping strategies. Drip irrigation, being one of the important water management technologies, was being adopted. Thus, in regions where there was severe water and labour scarcity, first there was a shift from labour and water-intensive crops such as vegetables, sugarcane, cotton, paddy, etc. to less labour-intensive crops such as coconut, and it was being followed by drip adoption. As drip irrigation saves human labour substantially by reduction in operations such as irrigation and weeding, water-loving crops such as banana and grapes were being planted following drip irrigation.

A significant shift towards crops such as coconut, grapes was commonly observed in the drip villages (Table 2). The main reasons were scarcity of human labour and of water. For this reason, a reduction in area under vegetables was also observed. Thus, the micro irrigation could be promoted in the regions with high scarcity of water and labour. As a cropping pattern decides the adoption and suitability of drip irrigation, widespread adoption of micro irrigation could be promoted in the regions where shift towards crops like coconut and banana is common.

Table 2. Drip irrigation and cropping pattern changes in study farms in Tamil Nadu

(Per cent)

Crops	Drip villages		Control villages	
	Before	After	Before	After
Banana	15.13	16.31	24.91	24.45
Turmeric	0.0	7.1	-	2.47
Sorghum	14.78	2.5	20.36	19.77
Ragi	4.19	0.0	-	-
Maize	8.48	6	6.89	6.38
Cotton	3.19	0.0	-	-
Sugarcane	-	-	11.85	11.17
Coconut	4.68	22.52	8.25	8.02
Grapes	18.82	24.05	-	-
Vegetables including tomato	30.73	21.52	27.74	27.74

Source: Field survey during 2007-08

Transition Probability and Steady State Probability of Changes in Cropping Pattern

Significant changes in the cropping pattern were observed in the study area. As the changes in cropping pattern favour the adoption of drip irrigation technologies, we were also interested in studying the type of transition that has taken place in the cropping pattern. For this, employing Markov chain analysis, the transition and steady state probabilities were computed and have been presented in Table 3. Markov analysis is a way of analysing the current movement of variable in an effort to predict its future movement. In the transition probability matrix, the rows identify the current state of the cropping pattern being studied and the columns identify the alternatives to which the cropping pattern could move. Here, the row probabilities are associated with crops retention and move to other crops (i.e. shift to other crops), while the column probabilities are associated with crops retention and move towards the crop (i.e. shift towards the crops,

Table 3. Transition probability and steady state probability of changes in cropping pattern in Tamil Nadu

Crops	Sorghum	Banana	Coconut	Maize	Tomato	Grapes	Vegetables	Others
Sorghum	0.03	0.17	0.24	0.06	0.19	0.23	0.02	0.06
Banana	0.01	*0.57*	0.22	0.02	0.06	0.06	0.02	0.04
Coconut	0.04	0.07	*0.75*	0.01	0.04	0.09	0.00	0.00
Maize	0.04	0.18	0.18	*0.29*	0.15	0.13	0.00	0.04
Tomato	0.05	0.09	0.21	0.02	*0.42*	0.11	0.06	0.05
Grapes	0.01	0.01	0.07	0.00	0.02	*0.87*	0.01	0.01
Vegetables	0.03	0.12	0.20	0.06	0.18	0.12	*0.24*	0.05
Others	0.00	0.20	0.12	0.08	0.08	0.19	0.05	*0.29*
Fallow	0.06	0.14	0.26	0.08	0.20	0.14	0.04	0.08
Steady state probabilities	0.02	0.10	0.32	0.01	0.07	0.44	0.01	0.02

gain to the particular crop). The transition probability presented in the Table 3 depicts the cropping pattern changes over time.

The diagonal elements represent probability of retaining the same crop in future. For instance, the probability of retaining banana crop was worked out to be 57 per cent. Similarly, for coconut the probability of retention was 75 per cent. The analysis shows that the probability of shifting of the area under maize to banana was 18 per cent, to coconut was 18 per cent, to tomato was 15 per cent, to grapes was 13 per cent and to other crops was 4 per cent. The probability of retention of maize crop was 29 per cent. Similarly, the vegetables have shown retention probability of only 24 per cent. The probability of shifting area of vegetables to banana was 12 per cent, to coconut was 20 per cent, and to grapes was 12 per cent. What will happen in the future if this pattern of changes in the cropping pattern occurs? If this kind of transition continues, around 32 per cent of the cropped area will assume area under coconut and grapes will assume 44 per cent of the total cropped area. This ensures better scope for a wider adoption of drip irrigation in the region.

The Markov analysis has lucidly shown that the existing trend in cropping pattern changes will result in a new cropping pattern which will favour wider adoption of drip method of irrigation in the future.

Impact of Drip Irrigation on Agricultural Production

To assess the impact of drip irrigation on agricultural production, the economics of drip irrigation were worked out for the major crops. The adoption of drip irrigation has significant positive impact on the cost of cultivation and cost of production and returns of the farmers. The economics of banana cultivation revealed that the cost of labour was significantly lower under the drip method (Rs 9761/ha), which was 69 per cent less than in the control villages (Rs 31487/ha). The drip method significantly saves the human labour involved in crop production activities. It also saves irrigation labour and weeding labour. On an average, the human labour days used for weeding banana were 17 labour days / ha under drip method and 60 labour days/ha under flood method of irrigation. The drip method saved nearly 71 per cent of weeding labour when compared to flood method of irrigation. The irrigation labour has been worked out to be 168 labour days /ha under flood method and 18 labour days/ha under drip method of irrigation. Due to this, the cost of cultivation was significantly less under drip over the flood method.

The reduction in cost on human labour has a significant bearing on the cost of cultivation. Though, the cost of installation of drip equipments and maintenance is incurred by the drip farmers, the cost of cultivation per hectare has been worked out to be Rs 80396/ha in drip farms, which is around 23 per cent less than in the control villages (Rs 109685/ha). The gross margin per hectare has been found as Rs 200232/ha in drip and Rs 163048/ha in control farms. It clearly shows that drip method of irrigation has resulted in an increase of 22 per cent of gross margin over the control. As the adoption of drip irrigation saves considerable water and energy, the water and energy productivity is significantly more in drip farms than the control villages where the flood irrigation is followed. For instance, the water productivity has been worked out to be 7.4 kg/M^3 of water in drip farms and 4.9 kg/M^3 of water in control villages. Significant difference in energy productivity has also been noticed. The returns per unit

Table 4. Economics of crop production for banana in sample farms in Tamil Nadu

(Per hectare)

Particulars	Drip villages	Control villages
Quantity of water applied (M^3)	8979*	12669
Quantity of energy consumed (kWh)	2219*	8294
Cost of labour (Rs)	9761*	31487
Capital (Rs)	80369*	104351
Yield (tonnes)	60.34*	57.79
Gross income (Rs)	280602*	267400
Gross margin (Rs)	200232*	163048
Yield per unit of water (kg/M^3)	7.4*	4.9
Yield per unit of energy (kg/kWh)	28.6*	7.2
Returns per unit of water (Rs/M^3)	23.8*	13.3
Returns per unit of energy (Rs/kWh)	92.3*	19.8

Source: Field survey during 2007-08
Notes: *indicates that values are significantly different at 1 per cent level from the corresponding values of control village

of water and energy have shown that drip farms have significantly higher returns over the control. Thus, one could conclude that the drip adoption would be a viable technology with significant bearing on the private profits.

The economics of coconut cultivation in drip and control villages has revealed that the cost saving due to reduction in labour was 69 per cent (Table 5). Similarly, the cost of cultivation was considerably lower under the drip method, registering a reduction of 15.5 per cent.

The impact of drip irrigation on resource saving and productivity enhancing was highly significant in grapes. Since grape cultivation is sensitive to water stress and involves huge labour for irrigation, weeding, training and pruning, the drip could result in significant savings in water and labour, leading to reduction in cost of cultivation (Table 5).

In grape cultivation, the cost incurred on human labour was Rs 17324/ha in drip farms and Rs 29433/ha in control farms with an average reduction of 41 per cent (Table 5). Also, there was a reduction in the cost of cultivation by 15.6 per cent in drip farms over control farms. The gross margin across farms indicated that the drip farms achieved relatively higher returns with a given price of output when compared to control farms mainly due to difference in yield. The physical productivity of water and energy was significantly higher in drip than control farms.

The analysis of economics of crop cultivation under drip and flood methods of irrigation has revealed that the former has a significant impact on resources saving, cost of cultivation, yield of crops and farm profitability. The physical water and energy productivity was significantly high in drip than flood method of irrigation. One could conclude that the drip has a significant bearing on the private costs and hence on profit of farmers.

Table 5. Economics of crop production for coconut and grapes in sample farms in Tamil Nadu

(Per hectare)

Particulars	Coconut		Grapes	
	Drip villages	Control villages	Drip villages	Control villages
Quantity of water applied (M^3)	3096*	10855	5195*	6757
Quantity of energy consumed (kWh)	917*	7423	550*	3124
Cost of labour (Rs)	3733*	12024	17324*	29433
Capital (Rs)	27510*	32560	50690*	60124
Yield ('00 nuts in coconut and tones in grapes)	227*	201	22.84*	19.45
Gross income (Rs)	105443*	86419	246668*	233454
Gross margin (Rs)	77933*	53859	195978*	173330
Yield per unit of water (nuts/M^3 or kg/M^3)	7.3*	1.9	4.7*	3.1
Yield per unit of energy (nuts/kWh or kg/kWh)	28.6*	2.6	43.7*	6.2
Returns per unit of water (Rs/M^3)	25*	5	41*	27
Returns per unit of energy (Rs/kWh)	98*	7	378*	55

Source: Field survey, 2007-08
Note: * indicates that the values are significantly different at 1 per cent level from the corresponding values of control village

Conclusions

The study has revealed that adoption of drip irrigation technology has increased the net sown area, net irrigated area and thereby has helped in achieving higher cropping intensity and irrigation intensity. It has been found that there is a significant shift towards crops such as coconut, grapes and banana from annual crops like vegetables, sugarcane and the like. The main reasons have been found as scarcity of human labour and water. As the cropping pattern decides the adoption and suitability of drip irrigation, widespread adoption of micro irrigation could be promoted in the regions where shift towards crops like coconut, banana and grapes are common. The analysis of economics of crop cultivation under drip and control has revealed that the drip method of irrigation has a significant impact on resources saving, cost of cultivation, yield of crops and farm profitability. The physical water and energy productivity is significantly high in drip over the flood method of irrigation. One could conclude that the drip has a significant bearing on the private costs and benefits and hence on profit of farmers. Thus, our policy focus may be tilted towards the promotion of drip irrigation in those regions where scarcity of water and labour is alarming and where shift towards wider-spaced crops is taking place.

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