



International Journal of Research in Agronomy

E-ISSN: 2618-0618
P-ISSN: 2618-060X
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NAAS Rating (2026): 5.20
www.agronomyjournals.com
2026; SP-9(3): 156-163
Received: 21-01-2026
Accepted: 25-02-2026

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Social benefit-cost analysis of private investment on drip irrigation

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DOI: <https://www.doi.org/10.33545/2618060X.2026.v9.i3Sb.5095>

Abstract

Drip irrigation is widely advocated to increase water use efficiency in agriculture as water scarcity is one of the key factors hinders agricultural sustainability. This paper employs social benefit-cost analysis (SBCA) framework to assess the private and external costs and benefits of adopting drip irrigation across two agro-climatic zones of Tamil Nadu, India. It is found that the drip irrigation has resulted in reduced water and energy consumption, increased water and energy productivity of crops, and profitability. The Social Benefit-Cost ratio (SBCR) is worked out to be 4.09 and 4.05 including subsidy with a discount rate of 2% and 5% and without subsidy the SBCR is worked out to be 3.71 and 3.68 respectively. This confirms that the wider adoption of drip irrigation produces sufficient social benefits and huge subsidization on drip irrigation is justified. Our policy focus may be tilted towards promotion of drip irrigation in regions where water and labour scarcity is alarming.

Keywords: Drip irrigation, social benefit-cost analysis, private cost, external cost

1. Introduction

The demand for food increases as the world's population grows, placing strain on the water resources required for agriculture (Pereira, 2017; Fraiture *et al.*, 2010) ^[17, 4]. Around 2855.46×10^9 m³ of water is extracted for agriculture purpose annually worldwide, with Southern Asia accounting for about 1018.84×10^9 m³/year. Irrigated agriculture has a water use efficiency of 0.67 US\$/m³, and the agricultural sector is responsible for 13.27% of the world's water stress (FAO-AQUASTAT) ^[3]. For food security and sustainable agricultural development, efficient water management is essential. Ineffective water management techniques might result in a shortage of water and lower the agricultural productivity (Pereira, 2017; Namara *et al.* 2010) ^[17, 13].

In contrast to conventional methods of irrigation, drip method of irrigation delivers water directly to the plant roots which minimises evaporation and conserves water and nutrients (Shaik, 2021; Suresh Kumar and Palanisamy, 2011) ^[18, 22]. Although the agriculture sector in India utilizes above 80% of the water, the efficiency of water use is between 30% to 40% only, indicating that much room for improvement exists. The water use efficiency can rise by 80-90% in a drip irrigation system that is properly planned and maintained (Sivanappan, 1994) ^[19].

Few major socioeconomic advantages that drip irrigation technology offers include increased agricultural productivity, resource conservation and environmental sustainability. It enhances agricultural yield for banana, coconut, grapes and turmeric by 4.41%, 15.1%, 16.9% and 22.8% respectively. For the crops arecanut, coconut and nutmeg the yield improvement ranges between 13% to 47%. It also lowers well failure rates, increases water use efficiency and uses less energy. It also increases the area that is irrigated and net sown, which makes it a sustainable alternative in areas with limited water resources (Suresh Kumar and Palanisamy, 2011; Chandran and Surendran, 2016) ^[22, 1].

Economic benefits are further highlighted by the cost benefit ratios for the different power sources utilized in drip systems; electric-powered systems have a benefit-cost ratio of 1.65. Drip irrigation has social costs like government subsidies and compelled infrastructure upgrades, but it also has beneficial externalities like off-farm employment and energy savings. For the crops sugarcane and banana monetary savings through electricity is found to be Rs.20.3 thousand per

hectare and Rs.11.01 thousand per hectare respectively. Similarly water saving is found to be Rs.1.1 lakh per hectare and Rs.69.9 thousand per hectare respectively.

Apart from social benefits and costs, some challenges faced in drip irrigation include emitter clogging, design limitations and socio-economic factors. The uniformity and effectiveness of irrigation are significantly impacted by emitter blockage, especially from chemicals brought on by fertigation and saline water. The inability of non-pressure compensated drip systems to maintain consistent water distribution over longer lateral lines can result in efficiencies. Farmers decision to use drip irrigation are heavily influenced by factors including labor demands, technical understanding and educational attainment. To improve knowledge on advantages of drip irrigation and its operational needs, awareness and training are crucial. Understanding these issues is also crucial for improving the drip irrigation efficiency and also to increase the adoption percentage among farmer community.

Building on this overview, the current paper investigates the following objectives (i) to estimate the social benefits and costs of drip irrigation, and (ii) to propose policy measures to promote greater use of drip irrigation throughout the state. The cost-benefit analysis of private investments is mostly limited to those costs and benefits internal to the project. The external benefits and external costs are intermittently included in public investment projects and it is seldom included in private

investments. In this paper, Authors capitalize on the strengths of the adoption of drip irrigation by developing a framework for social cost-benefit analysis (SBCA) approach to examine the social benefits of private investment under different subsidy regimes.

2. Methodology

2.1 Sampling framework

Two agroclimatic zones of Tamil Nadu state, India were taken for study. Two districts (Coimbatore and Erode in Western zone and Salem and Dhamapuri in North-western zone) in each zone were selected. In each district, two blocks were selected. Two villages with high rate of micro irrigation adoption were purposively chosen from the chosen blocks. Figure 1 shows the study region.

In each village, 25 farmers who adopted micro irrigation were chosen, along with 15 non-adopters and 10 dis-adopters, in order to investigate the adoption, dis-adoption and effects of micro irrigation on resource use, agricultural productivity and farm revenue. Farmers list on drip adopters were collected from the respective block Department of Agriculture and Horticulture to choose the farmers. Additionally made a conversation with the village people and private companies dealing with micro irrigation systems to prepare final list of sample farmers. As a result, 800 farmers were included in the sample.

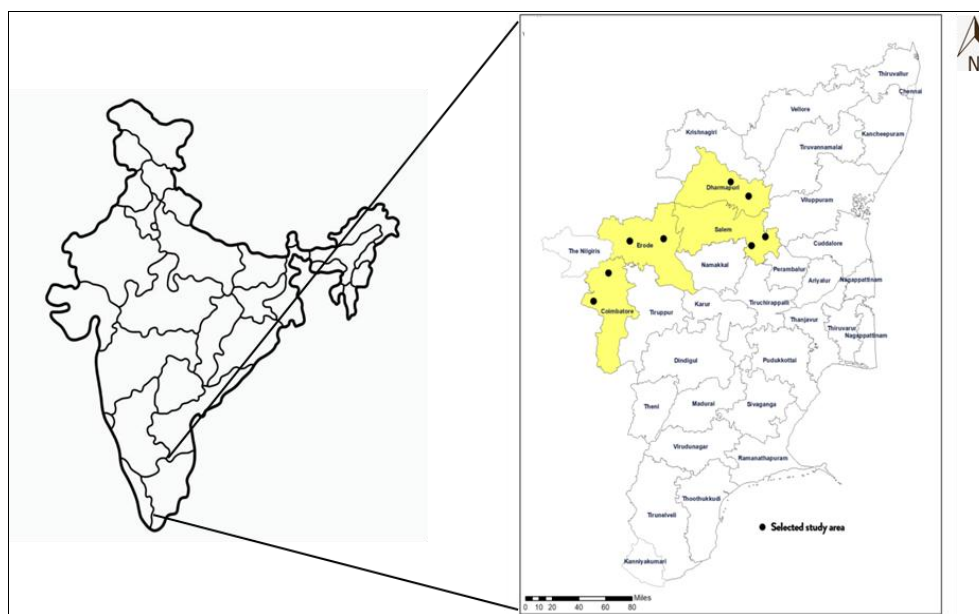


Fig 1: Study area in the western and northwestern zones of Tamil Nadu, India

2.2. Data

The necessary details from the respondent groups was acquired directly using the pre tested interview schedule. The primary data obtained from respondents include information on well investment, extraction and management, groundwater usage through different sources, production of crops which includes resource use and yield, farm revenue, drip irrigation adoption, and drip irrigation investments. This comprises asset position, education, and other socio-economic factors. The data were taken between June and September 2021. The reference year for the collected information was 2020-21, and the pre-adoption period is 2017-18.

2.3. Impact of drip adoption

The effect on various areas were compared between adopters

and non-adopters in order to investigate the physical and socio-economic implications of adopting drip irrigation. Data were obtained for both adopters and non-adopters for the two time periods namely before and after drip irrigation adoption.

2.3.1. Social benefit-cost analysis (SBCA)

The social benefit-cost analysis (SBCA) approach involves identifying, quantifying, and comparing the social benefits and costs of private investment in drip irrigation. Markandya *et al.* (2002) ^[12] define social cost as the total of private and external costs, and social benefit as the sum of private and external benefits. The private cost comprises the real costs spent by producers during production, whereas the private benefit represents the amount of benefits gained by the producers. The external cost is the expense to society incurred as a result of bad

externalities, whereas the external benefit is the gain derived from positive externalities.

The adoption of drip irrigation creates several externalities, both positive and negative, that have an impact on society as a whole (Dhawan, 2000) ^[2]. The positive externalities may include a decrease in the rate of well failure, a decrease in the cost of drilling new wells or deepening existing ones, and an increase in the amount of irrigation and water availability. The use of drip irrigation also results in negative externalities, such as a decrease in employment of human labour as a result of changes

in cropping patterns, such as the shift from labor-intensive annual cereal crop production to less labor-intensive tree production, and an increase in local villagers' consumption costs as a result of higher cereal prices brought on by lower local production. Externalities often occur when specific behaviour of producers or consumers have unintended effects on other producers or consumers. Externalities occur when consumers and producers do not evaluate all costs or benefits while engaging in consuming and production activities (Markandya *et al*, 2002) ^[12].

Table 1: Typology of Impact of Drip Irrigation Adoption on Environment and Economy

Cost/Benefit	Particulars
Private Costs	Huge capital investment for drip installation; periodical maintenance costs
Private Benefits	Increased yield and its quality leads to high output value; labour saving; expansion of cultivated area
External Costs	Substituting to high value crops from food grains may affect food security
External Benefits	Increased water use efficiency; Decreased energy consumption; Decreased well deepening cost; decrease in well failure

Source: Concept adapted from Dhawan (2000) ^[2], Kumar *et al.*, (2008) ^[10] and Suresh Kumar (2010) ^[21]

Positive externalities occur when a person or group's actions benefit others. Negative externalities occur when an activity taken by a person or group of producers has a negative impact on others. In an action that generates a positive externality, the social benefit outweighs the private benefit, whereas in an activity that generates a negative externality, the social cost exceeds the private cost.

The different positive and negative externalities created by drip irrigation were analysed and quantified to calculate the social benefit-cost ratio (SBCR). Adoption of drip irrigation generates a number of positive externalities, including increased water availability for irrigation, lower electricity energy consumption, lower well deepening costs, lower drilling costs for new wells/bore wells, and lower well failure rates. Thus, the social benefit in year 't' consists of both private and external benefits. The private benefits include agricultural output returns, while the external benefits include water and energy savings as a result of drip irrigation usage. Thus, the social benefit is evaluated by.

$$SB_t = \sum_{i=1}^n AR_i + \left[\frac{\sum_{i=1}^n \nabla_i A_i}{\sum_{i=1}^n A_i} \cdot \Omega + \frac{\sum_{i=1}^n \phi_i A_i}{\sum_{i=1}^n A_i} \cdot \Psi \right]$$

Where ∇_i denotes the decrease in water applied as a result of drip irrigation in m^3 , A_i is the area under crop i in hectares, Ω is the economic value of water ^[1] used in agriculture in the region in Rs./ m^3 of water (Gibbons, 1987) ^[6]. Similarly, the external benefits in the form of reduced consumption of power energy (Rs./ha) was estimated. ϕ_i represents the reduction in the energy consumption for irrigation ^[2] in agriculture due to drip irrigation,

A_i is the area under crop i in hectares, Ψ is the economic value of energy in Rs./ kwh ^[3]. The social cost includes private and external cost. The private cost includes the annual cost of drip irrigation systems ^[4], operation and maintenance cost of the drip irrigation system and crop production, and the external cost is the annual economic value of all negative externalities induced by drip irrigation.

$$SC_t = AIMC + \sum_{i=1}^n NR_i$$

The social benefit-cost ratio was calculated using the discounted cash flow method, taking into account the drip irrigation system's life and the discount rate. The SBCR is calculated as follows:

$$SBCR = \frac{\sum_{t=1}^T \frac{SB_t}{(1+r)^t}}{\sum_{t=1}^T \frac{SC_t}{(1+r)^t}}$$

Where

SBCR: Social benefit-cost ratio

SB_t : Social benefit in period 't'

SC_t : Social cost in period 't'

t: Lifetime of the project period

r: Social rate of discount

The following assumptions were made in order to calculate the SBCR: (i) the drip irrigation set's life span is taken into account

¹Gibbons (1987) ^[6] suggested that the marginal value of the water of each M^3 is the marginal physical product times the crop output price. Regression analysis was performed with yield as the dependent variable and water pumped as the independent variable. A quadratic production function was estimated. From the estimated production function, the value of water is determined by multiplying the marginal physical product of water (MPP) with the price of output (P_y).

²The cropwise electricity consumption was computed as under: A one HP pump run for one hour consumes 0.746 kwh of power. Accordingly, kwh for each crop = [(HP of pump) X (0.746 kwh) X (Number of hours of irrigation) X (No.of irrigation)]

³ The economic value of energy is Rs.6.46 /kwh which is the cost of producing a kwh by the state (Kumar, 2017).

⁴ The amortization of drip irrigation system is calculated as follows:

Amortised cost of Drip System=[(Compounded cost of drip system)*(1+i)^{AL}]/ [(1+i)^{AL}-1] where AL is the average life of a drip irrigation system.

Compounded cost of Drip irrigation system= (Initial investment on Drip system)*(1+i)^(2021-year of installation)

A discount rate of 5% is used in amortization, reflecting a long-term sustainable rate. The average life was assumed to be 7 years for drip irrigation system.

as seven years; (ii) two different discount rates (2% and 5%) were taken into consideration as alternatives representing different opportunity costs of capital in order to understand the sensitivity of investment to changes in capital costs; and (iii) it is assumed that the agricultural production technology of various

crops will remain constant for the duration of the calculation.

3. Results and Discussion

3.1 Farm and Irrigation Dynamics: Effect of Drip Irrigation.

Table 2: Size of holding and cropped area in sample households

Details	Drip Adopter		Non-Adopter		Dis-Adopter	
	Before	After	Before	After	Before	After
Farm Households Count	400		240		160	
Farm size (ha)	2.10	2.21***	1.43	1.49	1.70	1.88
Net sown area (ha)	1.53	1.91	1.30	1.42	1.37	1.51
Gross cropped area (ha)	1.95	2.52	1.34	1.50	1.80	2.08
Cropping intensity (%)	127.45	132.63***	103.08	107.14	131.39	137.75
Net irrigated area (ha)	1.40	1.70	1.04	1.16	1.32	1.38
Gross irrigated area (ha)	1.90	2.48	1.22	1.34	1.66	1.75
Irrigation intensity (%)	135.71	145.88***	117.31	115.52	125.76	126.81
Percentage of total cultivated area that is irrigated by wells (%)	97.44	98.41	91.04	89.33	92.22	84.13
Percentage of gross cultivated area that is drip irrigated (%)	.	89.68	.	.	.	.
Drip irrigation percentage as a percentage of total irrigated area	.	91.15	.	.	.	.

Source: Field investigation from June to September of 2021.

***, ** and * indicate values are significantly different at 1%, 5% and 10% levels from the corresponding values of non-adopters. The student 't' test was used.

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

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

Different patterns in landholding size and resource utilization after the deployment of micro irrigation (MI) technology are studied by a comparative analysis of sample farm households. The average landholding of MI adopters was 2.21 hectares, which was significantly larger than that of non-adopters (1.49 ha) and dis-adopters (1.88 ha). (Table.2) Given their higher ability to absorb the significant initial expenditure needed, this discrepancy implies that larger farmers are more likely to employ MI technology. The information backs up the idea that farm size has a significant impact on technology adoption, with larger holdings allowing for more flexibility in infrastructure construction and capital deployment.

The study also demonstrates that the implementation of MI improves cropped and irrigated regions in quantifiable ways. Improved cropping intensity was demonstrated by adopter's increased net sown area from 1.53 ha to 1.90 ha and gross cropped area from 1.95 ha to 2.52 ha. The percentage of the gross cultivated area that was irrigated by wells increased from

97.44% to 98.41%, indicating similar advances in irrigation measures. These results demonstrate the twofold influence of MI technologies: first, as a water-saving technique that enhances irrigation effectiveness on a farm and regional scale, especially in environments with limited land; and second, as a driving force behind the expansion of cultivated land where land availability permits. Adoption of micro irrigation has generally shown notable benefits for resource efficiency and agricultural productivity, highlighting its place in sustainable farming systems.

3.2 Cropping Pattern

Was a new agricultural practice adopted as a result of micro irrigation, or did crops adjust to micro irrigation in reaction to growing water scarcity? We examined and reviewed the cropping pattern modifications brought about by drip adoption in order to provide an answer for this question.

Table 3: Cropping Pattern Changes due to Drip Irrigation in Study Farms (%)

Name of the Crop	Drip Adopter		Non-Adopter		Dis-Adopter	
	Before	After	Before	After	Before	After
Rice	7.1	0.4	6.2	3.8	0.2	5.8
Maize	14.9	12.6	11.7	10.0	11.2	10.0
Groundnut	5.6	4.7	6.5	5.5	5.8	5.0
Sugarcane	11.8	11.2	11.8	9.7	11.0	12.4
Turmeric	14.1	16.2	13.1	14.9	11.1	14.0
Tapoica	8.9	13.7	8.9	11.8	15.7	10.6
Tomato	6.5	8.6	4.8	4.0	10.6	5.3
Onion	1.6	2.5	1.0	0.8	3.4	0.2
Brinjal	5.8	7.6	7.1	10.8	6.8	10.0
Coconut	18.1	16.6	21.2	19.0	18.0	17.1
Banana	3.1	2.3	3.6	2.2	1.9	1.3
Other crops	2.5	3.6	4.1	7.5	4.3	8.3

Source: Field investigation from June to September of 2021.

The two main issues impacting agricultural output are a lack of labor and water resource. These issues forces farmers to change their cropping patterns in favour of less labor-intensive and

water-intensive crops. Rainfed crops like maize, sorghum and others require minimal resources which are typically the focus of farmers. However, large farmers who have access to capital

employ wide range of coping strategies and water management techniques like micro irrigation. Farmers who adopt drip irrigation cultivate water intensive crops like sugarcane and bananas because it greatly reduces the amount of labor required for tasks like weeding and irrigation (Table.3).

3.3 Investments in Irrigation and the Distribution of Pump Horsepower

Growing groundwater shortages and cheaper electricity sources contributed to the degradation of the groundwater resources. It is claimed that lower power pricing policies have brought the marginal costs to zero for water and energy. So, farmers consequently make poor use of power and groundwater. Negative externalities such as over-pumping, changing crop

patterns towards more water-intensive crops, well deepening, increased well investments, pumping costs, well failure and abandonment and out-migration, are growing much more faster as a result of this cheaper power availability. Such cheaper electricity has led to negative externalities that are expanding at a far quicker rate, such as over-pumping, shifting crop patterns toward more water-intensive crops, well deepening, increased well investments, pumping expenses, well failure and abandonment and out-migration. In order to combat the resource's degradation, farmers heavily extract groundwater. These consist of expenditures for drip irrigation, deepening already-existing wells, building intermediate storage buildings and drilling new bore or dug wells (Table.4).

Table 4: Well and Irrigation Investment (Rs/Ha of GCA)

Details	Drip Adopter	Non-Adopter	Dis Adopter
Investments on			
Wells	29095 (41.3)	34315 (65.5)	32947 (63.9)
Electric Motors	8512 (12.1)	8848 (16.9)	9124 (17.7)
Surface storage tanks	6871 (9.7)	9207 (17.6)	9484 (18.4)
Drip irrigation	26025.91 (36.9)	.	.
Total investment on irrigation structures	70505*** (100.0)	52371 (100.0)	51556 (100.0)
Distribution of the Pump's horse power			
HP/pump	5.40	5.47	5.53
HP/GCA	3.60	4.87	3.89
HP/GIA	3.80	4.92	2.49

Source: Field investigation from June to September of 2021.

***, ** and * denote values that differ significantly from the comparable values of non-adopters at the 1%, 5% and 10% levels.

1 USD = INR 82.00

For adopters, the total amortised cost per acre is Rs.70505; for non-adopters, it is Rs.52371 and for dis-adopters^[5], it is found to be Rs.51556. Adopters of drip irrigation have higher overall fixed costs for wells, electric motors, intermediate water storage buildings, and drip irrigation structures than non-adopters and dis-adopters. The higher investment is mostly due to increasing investment in drip equipment.

In the total investment cost of Rs.70505, well investments account for 41.3% followed by drip irrigation equipment cost (36.9%), electric motors (12.1%) and surface storage tanks (9.7%) for drip adopters. Farmers were forced to build intermediate water storage facilities or dig open wells as a result of growing water shortages and poor discharge rates. These tanks store water that is pumped from a very deep borewell and used to irrigate crops. Horse power per hectare of gross cultivated area and gross irrigated area differs significantly between drip adopters and non-adopters.

3.4. Impact of drip irrigation

3.4.1. Yield of Crops and Productivity gains

Drip irrigation has been reported to increase yield in the crops:

⁵The amortization of irrigation structures is estimated as follows:

Amortised cost of well is calculated as $[(\text{Compounded cost of well}) \cdot (1+i)^{AL} \cdot i] / [(1+i)^{AL} - 1]$ where AL is the average life of a well.

Compounded cost of well is estimated as $(\text{Initial investment on well}) \cdot (1+i)^{(2008-\text{year of construction})}$

Amortisation uses a 5% discount rate, which is a long-term sustainable rate. In a similar vein, investments in conveyance, pump sets, electrical installation, surface storage tanks and drip irrigation structures were amortised, with an estimated AL of 30 years (based on the typical life of a well in the research area). In a similar vein, it was estimated that borewells would last 20 years on average, electrical motors 15 years, surface storage tanks 25 years and drip irrigation equipment 7 years.

maize (19.12%), tomato (16.31%), sugarcane (16.25%), coconut (14.89%), and tapioca (14.36%). The study findings show that improved production may be achieved with drip irrigation, which is consistent with previous research (INCID, 1994; Suresh Kumar, 2012; Narayanamoorthy, 2005; Narayanamoorthy, 2008; Narayanamoorthy *et al.*, 2018)^[23, 14, 15, 16]. The drip irrigation technology increases agricultural production primarily by reducing moisture stress and increasing water use efficiency.

3.4.2. Energy consumption by crops

The amount of water pumped is determined by the discharge rate, irrigation frequency, and pumping hours. The drip irrigation technique frequently requires fewer pumping hours even though it necessitates more regular irrigation. Drip irrigation is used for 128.3 bananas, 118.5 sugarcane, 96 turmeric, 65 tapioca, 36.5 tomatoes and 26.5 onions. But when using the flood method of irrigation, the frequency of watering is extremely low. Farmers irrigate their fields once in four to six days under the flood method and the number of irrigation is 58 for banana, 55 for sugarcane, 42 for turmeric, 36 for tapioca, 19 for tomato, and 16.3 for onion (Table.5). Under the flood method of irrigation, farmers need 20 -25 hours of pumping to provide irrigation in one hectare of land. The average pumping discharge rate⁶ ranges from 1.6 to 2.0 litres per second. Using the drip irrigation method, farmers usually irrigate the farm for three to five hours for each irrigation. The drip irrigation technique saves a lot of irrigation effort in addition to energy and water because it takes less time to irrigate a plot of land. The energy consumption for different crops⁷ indicates that the drip irrigation method saves a significant amount of energy because it needs less pumping hours. Drip-adopting farms consume 1886.8 kwh of electricity per hectare annually, which is 62.2% less than non-adopters (4986.5 kwh per hectare annually). When

compared to flood irrigation, drip farms use substantially less energy, according to crop-wise electricity use. The electricity consumption per hectare for bananas is 3101.1 kwh/ha, which is 55.65% less than that of the flood method of irrigation (6992.6 kwh/ha). The difference in electricity consumption between the two irrigation methods is evident; the main cause of the high electricity consumption under flood method of irrigation is extended pumping hours due to a lower discharge rate.

3.4.3. Impact of drip system of irrigation on agricultural production

The adoption of drip irrigation has resulted in reduced use of water, labour, energy, capital cost, and an increase in the yield of crops (Table.5). The labour-saving is significant in all the crops

and the consequent reduction in the cost of labour is varied from 5.3% in tomato to 29.2% in turmeric. The cost of cultivation is substantially lower with the drip method than with the flood approach since it saves a large amount of human labour for weeding and irrigation. The reduction in the cost of labour and the cost of cultivation of crops result in increased returns to farmers. The increase in the gross margin under drip irrigation over flood method of irrigation is ranged from 20% in banana to 86.9% in maize. The increase is significant in other crops such as onion (76.5%), tapioca (67.2%), tomato (53.4%), turmeric (45.2%), and sugarcane (39.2%). The increase in gross margin is attributed due to two reasons: (i) adoption of drip irrigation results in increased yield and (ii) reduction in the cost of cultivation mainly through labour saving.

Table 5|: Economics of cultivation of crops

Particulars	Maize	Sugarcane	Turmeric	Tapioca	Tomato	Onion	Banana
Number of irrigation (Nos.)							
MI Adopter	17.0	118.5	96.0	65.0	36.5	26.5	128.3
Non-adopter	9.0	55.0	42.0	36.0	19.0	16.3	58.0
Energy consumed (kwh/ha)							
MI Adopter	349.3	2959.7	2049.6	1387.8	764.6	533.8	3101.1
Non-adopter	642.7	5947.5	3907.6	2607.5	1395.6	1167.1	6992.6
Yield of crops (quintal/ha)							
MI Adopter	72.9	1488	64.5	301.1	332.3	110.6	420.9
Non-adopter	61.2	1280	58.1	263.3	285.7	98.9	375.2
Percent difference (%)	19.12	16.25	11.02	14.36	16.31	11.83	12.18
Cost of labour (Rs/ha)							
MI Adopter	28489.2	74056.5	69471.3	40900.0	76475.0	85926.9	130983.0
Non-adopter	33599.9	95130.2	98054.8	51500.9	80750.0	108500.6	170229.4
Gross margin (Rs/ha)							
MI Adopter	60645.9	239982.0	234460.2	86083.6	158110.6	148600.1	1067962.6
Non-adopter	32437.4	172429.8	161479.2	51478.9	103058.8	84160.3	888634.5
Yield per unit of water (kg/M³)							
MI Adopter	6.7	14.1	0.9	6.1	12.2	6.8	3.8
Non-adopter	2.4	6.5	0.6	2.4	7.2	2.9	2.7
Yield per unit of energy (kg/kwh)							
MI Adopter	20.9	50.3	3.1	21.7	43.5	20.7	13.6
Non-adopter	5.8	17.2	1.5	6.8	17.1	6.5	6.7
Returns per unit of water (Rs/M³)							
MI Adopter	55.5	22.7	32.0	17.4	57.8	91.6	96.3
Non-adopter	12.5	8.7	15.6	4.7	26.0	24.9	63.9
Returns per unit of energy (Rs/kWh)							
MI Adopter	173.6	81.1	114.4	62.0	206.8	278.4	344.4
Non-adopter	31.0	23.1	41.3	13.2	61.8	55.0	157.8

***, ** and * denote values that differ significantly from the comparable non-adopter values at the 1%, 5% and 10% levels

The physical water productivity (kg/m³ of water) for different crops indicates that drip irrigation results in higher physical water productivity when compared to the flood method of irrigation. In maize, the water productivity is projected to be 2.4 kg/m³ for non-adopters and 6.7 kg/m³ for drip adopters. When compared to the flood method of irrigation, the use of drip irrigation yields much higher returns per unit of water and energy utilised.

3.5. Social benefit–cost analysis of drip irrigation

The adoption of drip irrigation increases private profits on the one hand and involves considerable social costs and benefits on the other. With a huge amount of subsidies involved in drip irrigation, the social benefit-cost analysis of drip irrigation was performed to examine the effects of changes in public policies such as subsidies.

Table 6: Social benefit cost analysis for drip irrigation (Rs/ha/year)

Particulars	Without subsidy	With subsidy
Private costs and benefits		
Private cost	197321	182417
Private benefit	269899	284803
External costs and benefits		
Value of water saving	441259	441259
Reduced power consumption in agriculture	20024	20024
Total external benefits	461283	461283
Social costs and benefits		
Social cost	197321	182417
Social benefits	731182	746087
Social benefit cost ratio (SBCR)		
2% discount rate	3.71	4.09
5% discount rate	3.68	4.05

Social cost is the sum of Private cost and External cost

Social benefit is the Private benefit and External benefit

1 USD = INR 82.00

Drip irrigation method of irrigation is adopted for crops such as maize, sugarcane, tapioca, turmeric, tomato, onion, banana, and coconut. When subsidy is not taken into account, the private cost is Rs.197321/ha. Investment in drip irrigation systems raises private costs. According to a study conducted in Andhra Pradesh's Nalgonda district, the potential negative externalities include: (1) decreased labour absorption in agriculture, primarily as a result of labour-intensive crops being replaced by cash crops that rely on mechanised farming; (2) a decrease in wage rates due to the decrease in labour demand; and (3) an increase in food prices due to the decline in cereal production in the area, primarily as a result of the replacement of traditional food crops (Kumar *et al*, 2008) ^[10]. Nevertheless, no such phenomenon has been discovered in the present study area. Rather, pay rates are growing as a result of an increase in labour demand. Due mostly to a lack of labour, cropping patterns are changing from annual crops to permanent trees and from agricultural crops to high-value horticultural crops. Therefore, in areas where water and labour are limited, drip adoption has no negative externalities. Increases in food prices are negligible in complete markets. The social cost is equivalent to the private cost since there are no appreciable negative externalities in the study area.

Drip adoption creates large positive externalities in addition to private benefits like higher agricultural production. Water conservation and lower energy use are examples of the positive externalities. The actual savings of irrigation water is the largest external benefit in the region among the several positive externalities.

In order to maintain their agricultural production revenue, farmers would have been compelled to overuse groundwater if drip irrigation had not been implemented. Therefore, it is crucial to know how much water the farmers may have used up if they had utilised the traditional irrigation method in order to get the same yield from the drip-irrigated plots. To ascertain this, the value of water saved has been worked out by comparing the water consumed by non-adopters for various crops. The water utilised by drip adopters and non-adopters was compared because the disadopters had already stopped. The value of water saving due to drip irrigation is Rs. 441259/ha.

Adoption of drip technology in agriculture results in huge electricity savings. To irrigate one hectare of land using the flood method, farmers must pump for 20 to 25 hours. However, farmers often only irrigate for three to five hours at a period when using the drip irrigation method, which results in significant energy savings. The economic cost of supplying electricity was taken into consideration while monetising the

saved energy. Adoption of drip system results in an external benefit of Rs.20024/ha through energy savings. Farmers were forced to use their electric motors for longer periods of time due to water scarcity and a poor discharge rate, which increased energy usage.

The social cost is Rs.182417/ha and the social benefit is Rs.746087/ha when the subsidy is availed. Similarly, the social cost and social benefit is respectively Rs.197321/ha and Rs. 731182/ha when the subsidy is not availed. The social gains outweigh the social costs. Expanding the use of drip irrigation has large positive social effects and no negative externalities. We may thus draw the conclusion that drip irrigation is more advantageous in areas where human labour and water are scarce, as well as financially and socially feasible.

Two distinct discount rates—2% and 5%—were used to calculate the social benefit-cost ratio (SBCR). When the subsidy is taken advantage of, the SBCR in the research region is 4.09 and 4.05 with a discount rate of 2% and 5%, respectively. Drip irrigation has more social advantages than social costs, according to an examination of the costs and benefits. This demonstrates unequivocally that more widespread use of drip irrigation generates adequate societal benefits, and that Tamil Nadu's massive drip irrigation subsidies—which currently stand at 100% for small and marginal farmers and 75% for others—are warranted.

4. Conclusion

The present study states that adoption of drip irrigation exerts a great influence on the economic and environmental performance of farm production. Through direct delivery of water to the plant root zone, drip irrigation helps in reducing evaporation loss and improves water use efficiency. Also not only increases farm profitability and crop productivity but also significant savings in energy consumption. This energy savings along with improved water productivity, underscores the vital role of drip irrigation in promoting sustainable agriculture in water-scarce regions.

Social Benefit-Cost Analysis (SBCA) confirms the economic soundness and social desirability of drip technology. When government subsidies were considered, the social cost and social benefit were little higher than without subsidy, but in both the scenarios, the social benefit consistently outweighed the social cost. The high SBCR values show that drip irrigation conserves resources and lowers externalities, which results in significant net social gains and benefits to the broader agricultural sector.

As per the analysis result, public spending on drip irrigation is financially sound. To scale up the adoption rate, the government

need to continue the capital incentives and institutional facilities. Areas with water and labour scarcity and for wider spacing crops like bananas, sugarcane and coconut are the focus points where policy attention has to be given related to drip technology. Water use efficiency in canal and tank command areas are as low as 35-45% and 30-50% respectively. Drip system has to be incorporated into these conventional irrigation networks to minimize the efficiency gap and ensure guaranteed water availability for farming.

To achieve long term sustainability of drip irrigation system apart from infrastructural and financial support, it needs effective technical service delivery. Although it is mandatory for micro-irrigation companies to provide technical support for a minimum of three years after installation, the study observed that inadequate follow-up services remain a critical factor influencing dis-adoption among farmers. Hence, to address this issue, it is essential to strengthen institutional mechanisms for post installation monitoring, capacity building and maintenance assistance. User confidence and system durability could be significantly increased by enforcing more stringent compliance among service providers and promoting farmer training through public-private partnerships.

In conclusion, the study confirms that drip irrigation is not only a financially rewarding technology at the farm level but also a socially beneficial innovation with far-reaching implications for sustainable water management, energy conservation and agricultural resilience. Strengthening policy and institutional frameworks to ensure equitable access, technical support, and long-term maintenance will be vital in realizing the full potential of drip irrigation as a transformative instrument for achieving water security and climate -resilient agricultural growth in Tamil Nadu and other semi-arid regions of India.

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