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Economics, adoption determinants, and impacts of micro-irrigation technologies: empirical results from India

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Abstract Micro-irrigation technologies are promoted for various reasons in India. Despite the reported significant economic advantages, and the concerted support of the government and NGOs, the current micro-irrigation area in India remains an insignificant proportion of its potential. This paper analyzes: (1) the economics of alternative micro-irrigation technologies, (2) the determinants of adoption, (3) the poverty outreach of the different micro-irrigation systems, and (4) the sustainability implications of micro-irrigation adoption. In line with the findings of other studies, this study indicates that micro-irrigation technologies result in a significant productivity and economic gains. The most important determinants of micro-irrigation adoption include access to groundwater, cropping pattern, availability of cash, and level of education, the social status and poverty status of the farmer. Contrary to the expectations, the majority of the current adopters of low-cost micro-irrigation systems are the better-off farmers. The study indicates that the impact of micro-irrigation systems on the sustainability of groundwater resources depends upon the magnitude of the overall productivity gain following the shift from traditional irrigation method to micro-irrigation system, the pattern of use of the saved water, and the type and potential number of adopters.

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Introduction

In many parts of the world, the demand for available water resources is fast exceeding the economic supply, and the competition among the various sectors of the economy for the scarce water is becoming intense. In response to these conditions, policymakers, researchers, NGOs and farmers are increasingly pursuing various innovative technical, institutional and policy interventions to enable the efficient, equitable and sustainable utilization of the scarce water resources. Micro-irrigation technologies are believed to be one of such innovative intervention approaches. Originally, micro-irrigation was often associated with the capital-intensive, commercial farms of wealthier farmers. The systems used on large farms, however, are unaffordable for smallholders and are not available in sizes suitable for small plots. Recently, these technologies have gone through technical transformations from largely sophisticated and capital-intensive features to an almost input mode (Polak et al. 1997; Verma et al. 2004; Shah and Keller 2002).

A survey of literature on the impacts of micro-irrigation technologies indicates that they are usually promoted primarily for one or more of the following objectives:

1. As means to save water in irrigated agriculture and avert the water scarcity crises,
2. As a strategy to increase income and reduce poverty among the rural poor, and
3. To enhance the food and nutritional security of rural households (Narayanamoorthy 2003; Polak et al.1997; Shah and Keller 2002; Bilgi 1999; Upadhyay 2003, 2004).

The income and poverty reduction effects of micro-irrigation technologies are attained through substantial increases in farm income due to higher crop yields, better output quality, early crop maturity, realization of higher unit output prices, and reduced cost of cultivation—particularly for operations like irrigation and weeding. Micro-irrigation technologies enable the production and consumption of vegetables, particularly leafy vegetables, which are usually missing in the traditional staple diets of many cultures. However, the much espoused water saving attribute of micro-irrigation technologies is contentious.

There are two lines of thought regarding the water saving potential of micro-irrigation technologies. The first line of argument is that the adoption of micro-irrigation technologies results in net water savings, which is attained through substantial reduction in losses due to deep percolation, evaporation, and inefficient field conveyance and distribution system. For instance, water application can be reduced by 50–100% through the drip method of irrigation (Sivanappan 1994 in Narayanmoorthy 1997). Water saving is the main motive for the state governments of India to embark on the massive popularization of micro-irrigation technologies. However, the farmers' rationale for adopting these technologies may be different from the governments' policy objectives.

The second line of thought is that even though micro-irrigation technologies can result in water savings at the plot or field level, it may not translate into net water savings at a higher level of spatial scale such as the watershed or the basin (Molden et al. 2003). According to this line of thought, even at the plot level, the net water savings could be only modest if the phenomenon of return flows, much of which goes to recharge the underground water source, is considered. Thus, the adoption of micro-irrigation technologies may not automatically lead to real water savings.

Various studies in India have shown a considerable return to farmers' investment in micro-irrigation technologies (Dhawan 2002; Narayanamoorthy 1997; Verma et al. 2004; Sarkar and Hanamashet 2002) and substantial efforts have been made to disseminate these technologies through encouraging private involvement in the manufacturing and distribution of the technologies, and providing subsidies. Despite these efforts, however, the current areas of micro-irrigation systems remain an insignificant proportion of the potential. Thus, finding out why micro-irrigation technologies are not being adopted to the extent anticipated, is an important research issue. This paper presents the results of the study done to assess the adoption determinants, economics, and impacts of micro-irrigation technologies in selected villages of Maharashtra and Gujarat states of India.

Objectives

The paper specifically aims to:

1. Analyze the economics of alternative micro-irrigation technologies ranging from low-cost drip and sprinkler systems to the capital-intensive systems,
2. Identify the determinants of micro-irrigation adoption and assesses their relative importance,
3. Evaluate the poverty outreach of the different micro-irrigation technologies, and
4. Discuss other impacts of micro-irrigation technologies.

Based on the results of the analyses the paper generates some policy relevant conclusions and implications.

Data, analytical methods, and description of adoption variables

Sources of data

The data for this paper was obtained from a survey of a random sample of 448 farmers in Gujarat and Maharashtra in September and October 2003. The structured questionnaire survey was preceded by focus group discussions, and key informant surveys in the study locations. The following analytical models were used to analyze and interpret the resulting data.

The transcendental production function

To evaluate the technical and economic efficiency of the different micro-irrigation technologies and the associated agronomic inputs, we fitted a transcendental production function to the data and derived marginal productivities. The transcendental production function is an extension of the famous Cobb–Douglas production function and represents the neoclassical three-stage production process.[1] It can be viewed as a generalization of the Cobb–Douglas production function that has variable production elasticity and may be specified as follows:

$$Y = AX_1^{\alpha_1} X_2^{\alpha_2} X_3^{\alpha_3} \cdots X_n^{\alpha_n} \times e^{\left(\gamma_1 X_1 + \gamma_2 X_2 + \gamma_3 X_3 \cdots \gamma_n X_n + d_1 D_1 + d_2 D_2 + \cdots d_l D_l + \gamma_{12} X_1 X_2 + \cdots \gamma_{ij} X_i X_j\right)}, \tag{1}$$

where the Xs represent agronomic and irrigation water inputs (continuous variables), namely weeding cost (Rs/ha), seed cost (Rs/ha), pesticide (l/ha), irrigation water (pumping hour/ha), nitrogen (kg/ha), phosphorus (kg/ha) and potassium (kg/ha). And D is a dummy variable representing the different micro-irrigation technologies, namely conventional drip systems, conventional sprinklers, micro-tube drip systems, low-cost drip systems, and micro-sprinklers.

The transcendental production function specified in Eq. 1 can easily be log transformed to yield

$$\ln Y = \ln A + \sum_{\alpha_i} \ln X_i + \sum_i \gamma_i X_i + \sum_i \sum_j \gamma_{ij} X_i X_j + \sum_l d_l D_l, \tag{2}$$

where Y is output, α_i measures elasticity, X_i measures the level of continuous variable i, γ_i is the rate of change in the elasticity, γ_{ij} indicates the interaction effects between the continuous variables i and j (i, j = 1, 2, ..., n), d_l is a measure of the effect of the different micro-irrigation technologies or measures the deviation of the mean effect of dummy variable D_l (the different kinds of micro-irrigation technologies) from the overall mean effect (common intercept).

Optimization rules are used to define efficiency. From the output optimization problem, optimality conditions require that the efficient region of production is where the gain in output per extra units of X_i is increasing:

$$\frac{\delta Y}{\delta X_i} = \mathrm{MPP}_i \geq 0, \tag{3}$$

where MPP_i is the Marginal Physical Product of input X_i. The point beyond which output starts to decrease with additional units of X_i ($\mathrm{MPP}_i < 0$) is where the region of inefficiency begins. The condition for economic efficiency is derived from optimality conditions for the profit-maximizing firm, where profit (π) is computed as:

$$\pi = P \cdot Y(X) - x'R, \tag{4}$$

where P is the price of output, $Y(X)$ is the production function specified in Eq. 1, and x and R are vectors of inputs and input prices, respectively. Conditions for profit maximization require that:

$$P \cdot \left(\frac{\delta Y}{\delta X_i}\right) = P \cdot \mathrm{MPP} = \mathrm{VMP}_i = R_i. \tag{5}$$

Implying that it is economically efficient to continue using more units of input X_i up to the point where the value of the marginal product of an extra unit of X_i (VMP_i) is equal to its cost (R_i).

The logit adoption model

In the present context, micro-irrigation adopters are those farmers who used one or more of the micro-irrigation technologies being promoted at the time of the study by the government and NGOs on whole or part of their fields. The non-adopters or non-micro-irrigation farmers are those who have not used micro-irrigation or who do not own micro-irrigation equipment during the year of the survey. Therefore, the micro-irrigation adoption variable is a discrete-dichotomous choice variable (a farmer is either a micro-irrigation adopter or is not).[2]

In the instances where the adoption variable is binary (0/1), *logit* and *probit* models are most commonly used to analyze technology adoption processes (Aldrich and Nelson 1984; Feder et al. 1982). Here the *logit* model was used for analyzing the factors influencing the adoption of micro-irrigation technologies,[3] which is derived from the following logistic function (Eq. 6).

$$P_i = Pr(Y_i = 1) = \frac{\exp(Z)}{1 + \exp(Z)}, \tag{6}$$

[1] The limitation of the Cobb–Douglas production function is that it can represent only one stage of production at a time and assumes fixed production elasticities, which requires that average physical product and marginal physical product be at a fixed proportion to each other (See Debertin 1986).

[2] One needs to note that the operational definition of micro-irrigation adoption adopted in here does not take into account the extent or intensity of adoption of micro-irrigation technologies.

[3] For the explanation of the differences and similarities between these two models see Amemiya (1981) and Greene (2000).

$$Z = \beta_0 + \sum_{i}^{m} \beta_i X_i, \quad (7)$$

where P_i denotes the probability that the ith farmer has adopted micro-irrigation technology ($Y_i = 1$), β_0 is the intercept, β_is are the slope parameters in the model, and X_is are the independent variables. The natural log transformation of Eq. 6 will result into Eq. 8, which is known as the *logit* regression model.

$$\ln\left(\frac{p_i}{1 - p_i}\right) = \beta_0 + \sum_{i}^{m} \beta_i X_i. \quad (8)$$

Thus, the βs are interpreted as the change in the natural log of odds associated with a one-unit change in the explanatory variables and do not directly indicate change in adoption probability or marginal effects. The marginal effect (or the quantitative importance of the explanatory variables) for the logit model is expressed as follows:

$$\frac{\delta P_i}{\delta X_j} = \frac{\exp(z)}{1 + \exp(z)}\left(\frac{1}{1 + \exp(z)}\right)\beta_j. \quad (9)$$

The model was fitted using LIMDEP computer program.

Description of the hypothesized adoption variables

The most common variables used in modeling technology adoption processes are human-capital variables (e.g., level of education, age), attributes of the technologies, nature of the farming system as influenced by the interplay of various biophysical and socioeconomic variables, tenure system, resource endowment, risk and uncertainty, social capital, and social psychological factors (Feder et al. 1982; Rogers 1995; Leagans 1979; Buttel et al. 1990).

In the present case, the variables hypothesized to influence micro-irrigation adoption decisions are summarized in Table 1. The variables were selected based on literature reviews of the determinants of micro-irrigation adoption (Caswell 1999; Shrestha and Gopalakrishnan 1993; Sakks 2001), own understanding of the socioeconomic setting of the study locations, and the technical attributes of the micro-irrigation systems prevalent in the study locations. These variables may be conveniently classified into six groups as follows:

1. *Family size and demographic structure*. This group of variables includes number of household members and the proportion of household members whose ages are lower than 14 years or more than 65 years (or dependency ratio). These variables indicate the degree of labor availability in the household.
2. *Human capital variables* such as age of the household head, and years of schooling of the household head. The variable age may be a surrogate for many other socioeconomic variables including experience, wealth and conservatism. The direction of effect of this variable on micro-irrigation adoption decision depends on which of these dimensions dominates. The level of education augments extension services and is hypothesized to positively contribute to the micro-irrigation adoption probability.

Table 1 Description of variables included in the logit regression model

Variable	Units	Maharashtra				Gujarat			
		Adopters		Non-adopters		Adopters		Non-adopters	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
Family size	Number	4.5	1.1	4.3	1.3	4.3	1.5	4.5	1.2
Age of the household head (HH)	Year	44.7	12.4	45.2	14.9	43.9	12.0	45.2	11.9
Dependency ratio	Percentage	16.4	19.8	17.1	19.7	13.4	18.7	15.4	19.8
Years of schooling of the HH	Year	9.2	4.3	7.5	4.1	5.1	4.6	3.9	4.4
Proportion of high caste	Percentage	82.7	–	52.5	–	80.0	–	45.7	–
Depth of well	Feet	63.9	59.3	19.2	36.2	75.6	56.0	62.6	42.7
Access to ground water	Percentage	96.3	–	52.5	–	100	–	93.0	–
Power of the pump owned	Horse power	6.6	12.9	3.8	1.5	4.01	2.8	0.6	1.7
Share of cereals and pulses	Percentage	13.8	22.0	20.5	31.4	2.8	8.4	4.1	10.6
Share of fruit crops	Percentage	27.3	34.5	5.1	14.6	4.1	14.3	7.2	18.1
Share of vegetables	Percentage	7.2	16.6	7.9	22.1	6.0	13.8	2.2	7.6
Share of cotton and oilseeds	Percentage	35.3	32.5	47.3	34.2	75.4	26.5	72.0	24.2
Share of livestock	Percentage	6.4	12.2	5.9	12.5	4.1	8.5	3.7	7.0
Share of off-farm and non-farm	Percentage	4.2	13.8	4.4	15.1	6.9	16.2	8.0	15.6
Poverty index	Score	0.3	0.9	–0.7	0.8	0.2	0.9	–0.4	1.1

3. *Ownership of agro-wells and pumps and their technical attributes*. The propensity of agro-well owners to adopt micro-irrigation systems is expected to be higher than the surface- water irrigators mainly due to differences in the type of property rights associated with the two modes of irrigation. Whereas, surface water sources are owned publicly or communally groundwater sources are usually owned privately. Hence, ceteris paribus, agro-well owners have the motivation or incentive to use the available water as efficiently as possible through employing various techniques such as micro-irrigation systems. The technical characteristics of agro-wells (e.g., depth) and pumps (horsepower) impinge on the micro-irrigation adoption decision of owners due to implications for energy cost or severity of water scarcity in the wells.
4. *Cropping pattern or the farming system*. This group of variables was represented by the share of the different categories of crops grown and livestock kept in the total annual income of the farmers. The effect of cropping pattern or the farming system on the micro-irrigation adoption decisions is expected to be substantial because of the crop specificity of some of the available micro-irrigation systems.
5. *Other socioeconomic variables*. Included under this group are the caste or social status of the farmer, the poverty index value of the farmer created using the principal component analysis and the share of income from off-farm and non-farm activities. The high caste households are expected to have a higher probability of adopting micro-irrigation technologies. Similarly, farmers with a higher poverty index value have a higher likelihood of being micro-irrigation technology adopters. The share of non-farm and off-farm income variable is also hypothesized to increase the probability of adopting the technologies through providing additional cash for procuring micro-irrigation technologies, which are normally considered as capital-intensive.

Construction of poverty index

The high initial capital requirement of micro-irrigation technologies is the major constraint to their adoption among poor farmers. It was in response to this that NGOs such as International Development Enterprises (IDE) and Appropriate Technologies for Enterprise Creation (APPROTEC) have introduced low-cost alternatives to the conventional capital-intensive ones. However, there is little information regarding the adoption pattern of the different makes and modes of micro-irrigation technologies among the potential adopters differentiated by poverty status. Specifically, it is necessary to assess if the poorest section of the farming population is the prime beneficiaries of the low-cost micro-irrigation systems as originally envisaged.

This issue was investigated through:

1. Analyzing the relative poverty status of the adopters and non-adopters using what is known as the indicator-based poverty assessment tool. The indicator-based poverty assessment tool first identifies the strongest individual indicators that distinguish relative levels of poverty such as human resources (e.g., years of schooling, age, etc.), dwelling characteristics and assets (e.g., farm and household assets, etc.). Second, the method pools the explanatory power of the identified individual indicators into a single index using the principal component analysis (See Henry et al. 2003; Namara et al. 2003),
2. Grouping the farmers into five poverty strata (i.e., very poor, poor, middle, rich, and very rich), and
3. Analyzing the pattern of distribution of the adopters of the different kinds of micro-irrigation technologies in the five identified poverty strata.

Empirical results and analyses

Types of irrigation systems

In both of the study locations, crop production based solely on micro-irrigation use is rarely found. For adopters, micro-irrigation use is often complemented with flooding/furrow method of irrigation at least once during the cropping season. The farmers use micro-irrigation technologies: (1) to enable early planting (e.g., cotton and groundnut) so that the plant is already established at the time of the onset of rain during monsoon and makes efficient use of rainwater, (2) to safeguard crops against crop loss or yield reduction due to dry spell or early withdrawal of rain, and (3) to save groundwater for use during summer and Rabi seasons.

Different kinds of traditional surface and micro-irrigation systems were found in the study locations (Table 2). Among the traditional surface irrigation methods flooding was most common in Gujarat, while the furrow system was more prevalent in Maharashtra. Few fields were under rain-fed systems. The proportion of fields under rain-fed systems was higher in Maharashtra than in Gujarat. The crops under the rain-fed systems were maize, sorghum, pulses, and oil seeds.

Table 2 Types of agricultural water management systems observed in the study locations

Irrigation systems	Maharashtra		Gujarat	
	Area (ha)	%	Area (ha)	%
Traditional surface irrigation and rain-fed systems				
Flooding	58.3	9.3	440.0	53.8
Furrow	129.5	20.6	80.1	9.8
Ring or round method	0.0	0.0	9.4	1.1
Rain-fed	66.4	10.6	6.0	0.7
Micro-irrigation systems				
Pepsee or easy drip (AMIT)	16.6	2.6	27.0	3.4
Micro-sprinklers	0.0	0.0	90.2	11.0
Micro-tube drip	271.6	43.3	91.6	11.2
Conventional drip	85.4	13.6	30.8	3.7
Conventional sprinklers	0.0	0.0	43.5	5.3
Number of fields	327		461	

The micro-irrigation technologies can be categorized into two groups based on their technical, economic and social attributes. These are low-cost micro-irrigation technologies, and the commercialized state-of-the-art micro-irrigation systems. The low-cost micro-irrigation technologies include pepsee, easy drip, various kinds of IDE's affordable micro-irrigation systems, micro-sprinklers, and micro-tube drip systems. The later class of micro-irrigation technologies includes conventional drip and sprinkler systems.

The technical, economic, and social attributes that distinguish the low-cost micro-irrigation systems from commercial state-of-the-art micro-irrigation systems are: low initial capital requirement, dependence on local manufacturing capacity, quick pay back period, lower pressure requirement, ease of technical understanding by users, adjustable to the smaller plot sizes, and compatibility with local micro-entrepreneurship. However, the low cost micro-irrigation systems result in less uniformity of irrigation application and have less operational convenience than the state-of-the-art micro-irrigation systems. The successful adoption of micro-irrigation technologies requires the fulfillment of the following three basic factors: (1) the technologies need to be technically and economically efficient, (2) the target beneficiaries need to be aware of or knowledgeable about the technical and economic superiority of these technologies, and (3) the technologies must be accessible to the potential users. The subsequent sections analyses these issues in some detail.

Yield responses

The results of the transcendental production function fitted to the data to assess the yield responses of the different agronomic and water management inputs are presented in Table 3. For all of the three crops considered (banana, groundnut, and cotton) the use of micro-irrigation technologies generally resulted in a significant yield improvement over the traditional irrigation practices. The transcendental yield response function also indicates that for banana and cotton, yield response to low-cost drip irrigation is lower than that for conventional drip. For groundnut, the response to sprinkler irrigation is by far better than that to drip irrigation. Dhawan (2002) also reported similar observations. In addition, farmers in Gujarat claim that the use of drip technology for groundnut is marred by many technical problems. The coefficient for the level of irrigation water use (as indicated by pumping hour per ha) in groundnut response function is positive both in the actual level and log form, implying that the farmers are currently applying an insufficient level of irrigation water to groundnut.

Among the agronomic inputs, the highest banana yield response was observed for pesticide application followed by potassium. The coefficients for the banana yield response to phosphorus suggest that the farmers are currently applying this input above the normally required rate. For groundnut, the highest responses were observed for weeding and seed cost, respectively. However, the groundnut yield responses to agronomic inputs are not statistically significant. Most of the agronomic inputs included in the cotton yield response function are statistically significant. Among these, the highest yield response was observed for seed input followed by nitrogen.

The synergistic effect of the various agronomic inputs can be observed from the positive interaction effect coefficients (γ_{ij}s). Pesticide-by-seed interaction effect is significant for banana and cotton. This shows that the yield advantage of investments in pest control depends on the type of the variety used. Similarly, the significant seed-by-weed interaction effect for cotton implies that the response to the weeding efforts of the farmer depends on the weed competitiveness and yield potential of the cotton variety used.

Technical and economic efficiency

The technical and economic efficiency parameters (i.e., MPP and VMP) for different micro-irrigation technologies derived from the fitted transcendental response functions discussed in the preceding section are presented in Table 4. The MPP values indicate an extra yield advantage that a farmer obtains when shifting from the traditional irrigation methods to micro-irrigation practice. The marginal physical productivity values shown in Table 4 indicate that the use of micro-irriga-

Table 3 The transcendental regression model results

No.	Variables	Banana		Groundnut		Cotton	
		Coefficients	t	Coefficients	t	Coefficients	t
1	Constant	3.172	1.408	–1.097	–0.630	–5.158	–3.635***
2	Estimates of γ_i's (agronomic and water management inputs in levels)						
	Weeding	–0.004362	–0.831	–0.0001653	–1.251	–0.01429	–1.169
	Seed	–0.0000331	–0.633	0.00000424	0.088	–0.0005785	–3.820***
	Pesticide	–0.378	–2.121**	–0.01156	–0.282	–0.05139	–1.500
	Pumping	NA	NA	0.001147	0.516	–0.0007448	–0.612
	Nitrogen	–0.001618	–0.985	–0.002253	–0.908	–0.006425	–3.054
	Phosphorus	0.003645	1.685*	NA	NA	–0.002535	–0.474
	Potassium	–0.003698	–1.251	NA	NA	NA	NA
3	Estimates of α_i's (agronomic and water management inputs in natural log form)						
	Weeding	0.485	2.324**	0.175	1.319	0.0782	0.348
	Seed	–0.08461	–0.38	0.237	1.177	0.612	3.501***
	Pesticide	0.647	1.343	0.08841	0.713	0.321	2.743***
	Pumping	NA	NA	0.05303	0.410	0.225	2.432**
	Nitrogen	0.196	0.63	0.03285	0.218	0.593	2.670***
	Phosphorous	–0.524	–1.589	NA	NA	0.04591	0.194
	Potassium	0.575	1.854*	NA	NA	NA	NA
4	Estimates of d_i's (micro-irrigation technologies)						
	Conventional drip	1.214	3.138***	NA	NA	1.162	3.516***
	Low-cost drip	1.05	2.997***	NA	NA	0.911	3.214***
	Micro-tube drip	NA	NA	0.511	1.787*	0.627	3.779***
	Micro-sprinkler	NA	NA	0.650	2.876***	NA	NA
	Conventional sprinkler	NA	NA	0.591	2.012**	NA	NA
5	Interaction γ_{ij} (among selected agronomic and irrigation water input variables)						
	Pest by Seed	0.0000124	1.954*	NA	NA	0.0000116	1.690*
	Seed by weed	0.0000003	0.478	0.00000001082	1.308	0.0000071	2.444**
	Pest by weed	NA	NA	NA	NA	0.0003578	0.878
	Pump by seed	NA	NA	NA	NA	0.0000005	0.594
	Nitrogen by potassium	0.0000066	1.041	NA	NA	NA	NA
	Adjusted R^2	0.277		0.108		0.391	
	F statistic	2.687***		2.545***		4.848***	
	Durbin–Watson	1.753		1.832		1.882	
	N	76		180		115	

Notes: * Significant at 10%; ** significant at 5%; *** significant at 1%

tion technologies in banana, groundnut, and cotton cultivation is technically efficient (MPP > 0) and that except for groundnut the technical efficiency of conventional drip systems is superior to that of low-cost drip systems. The superior yield performance of conventional micro-irrigation systems relative to the low cost systems may at first glance contradict the observed occurrence of both systems at the same time in a given area or even in a given farm. However, these two systems may serve different purposes and are therefore not mutually exclusive. Low cost micro-irrigation technologies are primarily adopted to avert risk during drought years; extend the limited water to as much area as possible; facilitate pre-monsoon irrigation to capture rainfall and extend the area of irrigation; save the perennial crops such as orchards and coconut etc.

Table 4 The technical and economic efficiency of micro-irrigation systems

Crop	Micro-irrigation technologies	MPP (q)	VMP (Rs)[a]	Investment cost	Subsidized investment cost
Banana	Low-cost drip	142.2	42,659	27,360	13,680
	Conventional drip	181.2	54,353	55,000	27,500
Groundnut	Micro-sprinklers	6.96	10,301	22,239	11,120
	Micro-tube drip	4.35	6,440	29,652	14,826
	Conventional sprinklers	5.21	7,706	30,000	15,000
Cotton	Low-cost drip	7.26	11,916	10,081	5,041
	Micro-tube drip	4.99	8,201	17,087	8,544
	Conventional drip	9.26	15,199	45,825	22,913

[a] Price of banana was estimated at Rs 300 per quintal

The yield advantage of the use of drip systems in groundnut cultivation is lower than that of the sprinkler systems. However, the choice between drip and sprinkler irrigation system also depends on the quality of groundwater. The farmers indicated that the use of sprinkler irrigation system in areas where the water is saline is quite risky as it may affect plant growth. It was in recognition of this risk that Agha Khan Rural Support Program (AKRSP) instituted two different subsidy regimes for farmers using sweet water and those using saline water. These two categories of farmers are entitled to a 33 and 50% subsidy, respectively.

The main motive of the farmers for using micro-irrigation technologies, particularly in groundnut, is to enable early planting by about a month than the normal practice. They do this for one or more of the following reasons: (1) to take the advantage of the available water so that they can spread the water to a larger extent and by the time the monsoon sets in the crop would be established, (2) to be able to harvest a normal crop even in case of early withdrawal of the monsoon, (3) to create a better soil moisture condition throughout the crop season to enable higher yields and better output quality due to better pod filling, and (4) to enable early harvesting, thus reducing labor cost. However, in case the rain continues during September (harvest time), the quality of the produce may be adversely affected. The other rationale for adopting micro-irrigation in groundnut is to save water for use in cultivation of pearl millet and vegetables in summer.

Technical efficiency alone does not guarantee economic efficiency. A farmer may well operate in the technically most efficient region of the production function but may still be judged as economically inefficient based on considerations of input–output price relations. Thus, to evaluate the economic efficiency of the different micro-irrigation technologies we need to consider the input–output price relationships. In the present case this was achieved through calculating the VMPs for each of the micro-irrigation technologies and comparing it with their respective initial investment costs under two scenarios, i.e., the actual and the subsidized costs (see Table 4).

From the results of the economic efficiency analyses the following inferences may be made:

- Even under the very conservative scenario of comparing the VMP with the actual investment cost,[4] except for micro-tube drip and conventional sprinklers under groundnut, all of the micro-irrigation technologies are economically efficient and the farmers can recuperate their initial investment capital within 1–3 years
- Subsidies further increased the profitability of investments in micro-irrigation technologies
- The magnitude of economic gains from investments in micro-irrigation technologies depends on the type of crop. Micro-irrigation technology use in banana is highly remunerative followed by cotton. The VMP for banana is almost equal to the initial investment cost. This means that the farmers can recuperate the investment cost within 1 or 2 years of use, and
- An investment in conventional drip systems is economically more rewarding than that in low cost drip systems

One of the advantages of micro-irrigation technologies recognized by the sample farmers in this study and often also claimed by many other similar studies is that they enhance the productivity of other agronomic inputs in addition to that of water. To investigate these effects we fitted a separate transcendental response function for micro-irrigation technologies and traditional irrigation methods for groundnut and cotton and calculated MPP and VMP values (see Tables 5, 6). The results for groundnut are entirely consistent with our expectations in that the calculated MPP and VMP values under sprinkler irrigation systems are higher than that for traditional irrigation methods. Thus, micro-sprinklers do enhance the marginal productivity of other agronomic inputs. However, under traditional method of irrigation, the farmers are currently applying more water and nitrogen to groundnut than the economically justifiable amount.

The results for cotton are mixed in that contrary to the expectations the marginal physical productivity figures for seed, phosphorus and pesticide are higher for traditional irrigation methods than that for drip irrigation system. However, there are justifiable reasons for these anomalies. For instance, farmers claim that with drip method of irrigation cotton plants are not able to make full use of Diammonium Phosphate applied as basal and that in most cases the fertigation tank attached to the micro-irrigation system is used for applying only liquid urea. The explanation for the unexpected results of seed and pesticide inputs is related to the higher adoption rate of Bt cotton[5] variety

[4] Ideally the VMP figures ought to be compared to the annual ownership cost of mico-irrigation technologies, which obviously is a fraction of the initial investment costs.

[5] Bt cotton is a genetically modified seed, created by inserting a gene from Bacillus thuringiensis (Bt), a naturally-occurring soil bacterium, so that the plant produces Bt toxins which kills bollworms.

Table 5 Technical and economic efficiency of other agronomic inputs for groundnut under different irrigation methods

Agronomic inputs	Unit input prices (Rs)	Traditional methods		Sprinkler systems	
		MPP (q)	VMP (Rs)[a]	MPP (q)	VMP (Rs)
Nitrogen (kg)	10.50	–0.014238074	–21.1	0.02554	37.8
Pesticide (l)	252.0	0.233088759	345.0	0.60806	899.9
Weeding (Rs)	1	0.001738573	2.6	0.00233	3.4
Seed cost (Rs)	1	0.000638345	0.9	0.00107	1.6
Pumping (h)	32.5	0.014114507	20.9	0.03340	49.4

[a] Price of groundnut was estimated at Rs 1,480 per quintal

Table 6 Technical and economic efficiency of other agronomic inputs for cotton under different irrigation methods

Agronomic inputs	Unit input prices (Rs)	Traditional methods		Drip systems	
		MPP (q)	VMP (Rs)[a]	MPP (q)	VMP (Rs)
Nitrogen (kg)	10.5	–0.0103657	–17.0	0.001102	1.8
Phosphorus (kg)	16.2	0.0601041	98.7	0.016049	26.4
Pumping (h)	32.5	0.0135367	22.2	0.036285	59.6
Weeding (man-days)	50.0	–0.1495965	–245.6	–0.10011	–164.4
Pesticide (l)	252.0	0.7827098	1285.2	0.541208	888.7
Seed cost (Rs)	–	0.0031636	5.2	0.001096	1.8

[a] Price of cotton was estimated at Rs 1,642 per quintal

among fields irrigated through traditional methods (flooding). Bt cotton variety is resistant to bollworm (i.e., enabling saving in pesticide cost) and also higher yielding. Similar to the case for groundnut, for cotton too, the farmers tend to apply more water and nitrogen than economically justifiable under traditional irrigation methods.

In summary, it was shown that the use of micro-irrigation in the cultivation of banana, cotton, and groundnut is both technically and economically justifiable (i.e., higher marginal physical productivities with the value of marginal physical products far greater than the resource cost). However, economics though important, is not sufficient to explain the farmers' adoption behavior. Thus, we now turn to the comprehensive analyses of the determinants of micro-irrigation adoption.

Factors influencing the adoption of micro-irrigation technologies

The analyses of the results of the logit regression model shows that most of the variables included in the model had the expected signs (Table 7). Family size and dependency ratio (i.e., the proportion of family members whose ages are less than 14 or more than 65), which were included to proxy the labor availability in the household, had an insignificant effect reflecting the lower labor requirement of micro-irrigation technologies as compared to the traditional irrigation methods.

The human capital variables are particularly of special interest regarding the micro-irrigation adoption process because of the fact that these technologies need technical and managerial skill for proper utilization. The age variable had a positive but insignificant effect on the adoption probability in both Gujarat and Maharashtra. Normally, one would expect the older farmers to have a lower chance of adoption of new innovations (Neil and Lee 2001). The observed unexpected sign of age in the present analysis may be because the age variable may have captured more the experience and wealth aspect than its conservatism dimension. Years of schooling and their interaction effect with the age variable had the expected signs but statistically significant only in Gujarat. The reason for the insignificance of these variables in Maharashtra may be that in this area micro-irrigation systems are being practiced by most of the farmers and are no more considered as new technologies. The negative sign for the age-by-years of schooling interaction effect could be due to the fact that younger farmers tend to be more educated than their older counterparts.

In line with our prior expectation, ownership of wells had an effect on the probability of adoption of micro-irrigation technologies in both locations. This is because well owners have a high degree of control on the water source and have the motivation to efficiently use the available water. Moreover, the depth of wells and the horsepower of the pumps owned had a significant positive impact on the likelihood of adopting these technologies, partly reflecting the farmers' power-saving motives.

Contrasting results were found for Maharashtra and Gujarat regarding the effect of cropping pattern on the adoption of micro-irrigation technologies. In Maharashtra, the significance of fruit crops in the cropping system had a significant effect on the adoption probability, while in Gujarat the share of vegetables, cotton,

Table 7 Factors influencing the adoption of micro-irrigation technologies

Variables	Gujarat			Maharashtra		
	Coefficient	*t*-ratio	Marginal effect	Coefficient	*t*-ratio	Marginal effect
Constant	–6.370	–1.748*	–0.99841	–7.0481	–2.408**	–0.4367
Family size	0.2079	1.176	0.03258	0.2701	1.266	0.01673
Age of the household head (HH)	–0.00009	–0.004	–0.00001	0.0438	1.164	0.00271
Years of schooling of the HH	0.2682	1.294	0.04203	0.2470	1.071	0.01531
Years of schooling-by-age interaction	–0.0045	–0.964	–0.00070	–0.0063	–1.250	–0.00039
Caste	1.0447	2.430**	0.16373	1.1903	2.420**	0.07375
Dependency ratio	–0.00045	–0.035	–0.00007	–0.0109	–0.846	–0.00068
Poverty index	0.5569	2.366**	0.08728	0.5385	1.600*	0.03337
Access to groundwater	3.1345	1.101	0.49126	4.4406	3.707***	0.27514
Depth of well	0.0020	0.459	0.00031	0.0068	1.034	0.00042
Horsepower of pump	0.5342	5.590***	0.08372	0.3258	2.722***	0.02019
Share of cereals and pulses	–0.0545	–1.761*	–0.00855	–0.0156	–0.943	–0.00097
Share of fruit crops	0.00320	0.144	0.000501	0.05075	2.232**	0.03145
Share of vegetables	0.0565	2.027**	0.008860	–0.0195	–1.035	–0.00121
Share of cotton and oil crops	0.01109	0.613	0.001738	–0.0067	–0.417	–0.00041
Share of livestock	0.01991	0.653	0.003120	0.05925	1.905*	0.00367
Share of off-farm and non-farm	–0.02189	–0.415	–0.00343	0.08905	2.598***	0.05518
Square of share of off-farm and non-farm	0.00060	0.537	0.000094	–0.00192	–3.024***	–0.00012
Log likelihood function	–82.79477			–63.22107		
$\chi^2(df)$	114.2133(17)***			135.2486(17)***		
Percentage of correct predictions	83.9			86.1		

Notes: * Significant at 10%, ** significant at 5%, *** significant at 1%

and oil seeds (mainly groundnut) had a positive influence on the adoption probability. The model also shows that in both locations, the higher the share of cereals and pulses in the cropping pattern the lower the probability of adoption of micro-irrigation technologies. However, this relationship was not statistically significant in Maharashtra. These findings are quite in line with the observation of the actual condition in the study areas. In Maharashtra, farmers mainly use micro-irrigation technologies for cultivating fruit crops such as banana and grape, while in Gujarat they use it largely for groundnut, cotton, and vegetables.

The effect of cropping pattern on micro-irrigation adoption process should be evaluated on short- and long-term perspectives. In the short run, micro-irrigation systems may bypass certain groups of farmers due to their inherent crop specificity. The bulk of the available micro-irrigation technologies are suitable for fruit crops, vegetables and cash crops such as cotton and groundnut. Therefore, farmers growing staple food crops such as cereals and pulses are not sufficiently benefiting from innovations in micro-irrigation technologies. In the long run, however, this scenario may be reversed due to two possible reasons: (1) the micro-irrigation engineers may innovate to develop systems for the crops which are currently not suited to micro-irrigation applications (Polak et al. 1997), and (2) the farmers may shift their cropping pattern to benefit from innovations in the micro-irrigation systems. The latter response will have substantial impacts on the water-resources economy of a watershed or basin.

Lastly, all of the socioeconomic variables, namely membership in the high-caste group, poverty status, and share of income from off-farm and non-farm activities in order of quantitative significance (see the respective marginal effect values) are significant in predicting micro-irrigation adoption decisions. On average, well-to-do farmers are most likely to adopt micro-irrigation technologies in both locations. A more in-depth analysis of the depth of poverty outreach of the different micro-irrigation technologies is presented in the next section.

In Maharashtra, the share of off-farm and non-farm income and its square had the expected sign. As the farmers' share of income from off-farm and non-farm sources increase the likelihood of adopting micro-irrigation technologies increases but only up to a certain point. This shows the importance of cash in the initial adoption decision of farmers. However, at higher levels of the share of off-farm and non-farm income the farmers are less likely to adopt micro-irrigation technologies because agriculture loses its importance and becomes no more the primary source of livelihoods. The situation for Gujarat is the exact opposite to that of Maharashtra. In the Gujarat case, as the share of income from off-farm and non-farm sources increases the likelihood of adopting micro-irrigation technologies decreases up to a certain point and then increases afterwards, reflecting the differences in the nature of off-farm and non-farm activities between the two study locations.

Depth of poverty outreach of alternative micro-irrigation technologies

The creation of a poverty index assigns to each household a poverty ranking score. The lower the score the poorer the household relative to all others with higher scores. The scores for micro-irrigation adopters and non-adopters can be compared to indicate the extent to which micro-irrigation technologies reach the poor. To reveal this, an appropriate definition of the poor has to be adopted. Since the target of NGOs engaged in the development and dissemination of low cost micro-irrigation technologies such as IDE and APPROTECH is the poorest section of the farming population, the sample farmers were divided into quintiles (i.e., very poor, poor, middle, rich, and very rich). First, the non-adopters were ranked based on their relative poverty score to create five poverty groupings, because the sample of non-adopters represents the unbiased sample of the general population. Then the cutoff values for the quintiles of non-adopters were used to group the micro-irrigation adopter's sample in to poorest, poor, middle, rich, and richest.

The poverty outreach of micro-irrigation technologies was assessed by drawing bar graphs of the distributions of the micro-irrigation adopting and non-adopting samples by poverty quintiles and then visually inspecting the pattern of distribution (see Figs. 1, 2, 3, 4). By default, the bars for non-adopters are expected to be equal in size across the poverty groups, and if micro-irrigation technologies are poverty-neutral, the

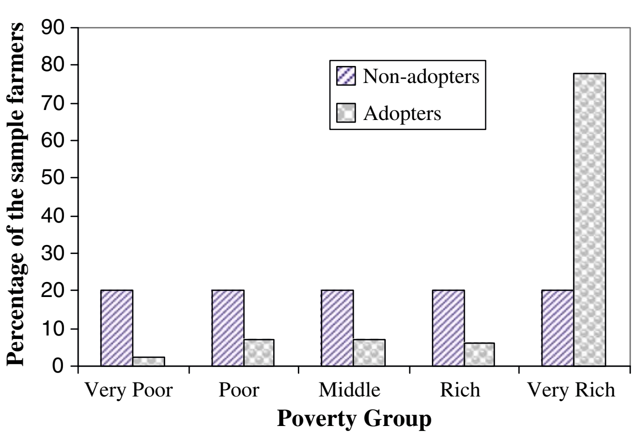

Fig. 1 Poverty outreach of micro-irrigation technologies in Maharashtra

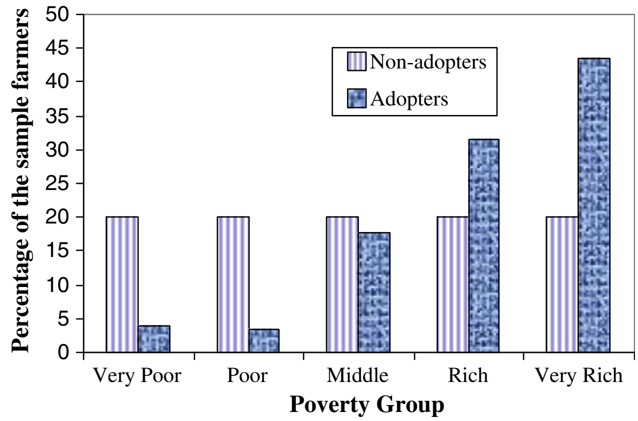

Fig. 2 Poverty outreach of micro-irrigation technologies in Gujarat

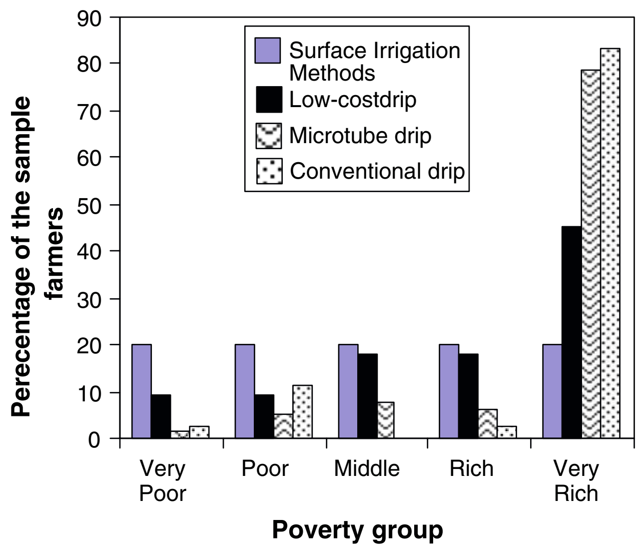

Fig. 3 Poverty outreach of different micro-irrigation technologies in Maharashtra

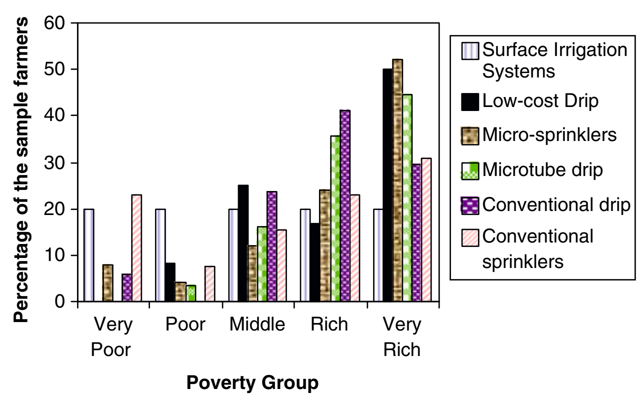

Fig. 4 Poverty outreach of the different micro-irrigation technologies in Gujarat

distribution for adopters is expected to follow a similar pattern to that of non-adopters. However, this is not true in the present case. As can be observed from Fig. 1, currently the largest proportion of micro-irrigation technology adopters in Maharashtra belong to the relatively very rich group. In Gujarat, the current micro-irrigation adopters are somewhat fairly distributed among the middle, rich and very rich groups (see Fig. 2). The slight improvement in the poverty outreach of micro-irrigation technologies in Gujarat may be due to the involvement of NGOs in the dissemination process. However, still in both Maharashtra and Gujarat, the poor and the very poor category are represented least.

But, the different micro-irrigation technologies have different levels of direct poverty impacts (see Figs. 3, 4). This can be inferred by visualizing how much the bar graph for the different kinds of micro-irrigation technologies deviate from that of the traditional irrigation method. The figures show that, in both Maharashtra and Gujarat, the very rich farmers represent the highest proportion of the low-cost drip technology adopters. In the case of Gujarat, none of the very poor farmers have yet accessed low-cost drip technologies. This observation contradicts with the most commonly held view that low-cost micro-irrigation technologies (low-cost drip such as *Pepsee*, easy drip, and micro-sprinklers) are easily accessible to poor farmers by virtue of their low initial capital requirements.

Impacts on cropping pattern

The shifts from the traditional flooding/furrow method of irrigation to the use of micro-irrigation have resulted in significant changes in the cropping pattern (see Table 8). However, the two locations greatly differ in cropping pattern, irrespective of the micro-irrigation adoption status, owing to differences in the agro-ecological settings.

A close scrutiny of the data displayed in Table 8 elucidates the following main points regarding the cropping pattern difference between adopters and non-adopters in Gujarat. These are:

- The proportion of micro-irrigation adopters growing cotton and vegetables is significantly higher than that of the non-adopters
- Lower proportions of micro-irrigation adopters cultivate cereals than non-adopters. In addition, the type of cereals grown by the two groups of farmers significantly differs. Adopters grow mainly wheat, while the non-adopters grow the traditionally drought-tolerant cereals such as pearl millet and sorghum
- Slightly higher proportions of non-adopter grow fruit crops than adopters. However, the types of fruit crops cultivated by the two groups are different. Micro-irrigation adopters produce high-value but water-intensive fruit crops such as banana, while the major fruit crop grown by non-adopters is coconut
- Micro-irrigation adopters cultivate more diverse crops during the year than the non-adopters. The adoption of micro-irrigation technologies helped some farmers to take *Rabi* and summer crops

Almost similar situations were observed in Maharashtra. The following points may be made regarding cropping pattern differential between adopters and non-adopters in Maharashtra.

- Unlike the case for Gujarat, there is no significant difference in the proportion of adopters and non-adopters growing vegetables
- The proportion of micro-irrigation adopters in Maharashtra that grow high value fruit crops such as banana is significantly higher than the non-adopters.
- The average banana area cultivated is also significantly higher for micro-irrigation adopters.
- Similar to the case of Gujarat micro-irrigation adopters in Maharashtra cultivate more diverse crops with in a year.

Table 8 Comparison of the cropping pattern of micro-irrigation adopters and non-adopters

No.	Crop	Gujarat		Maharashtra	
		Adopters	Non-adopters	Adopters	Non-adopters
1	Groundnut and other oil seeds	54.7	63.7	1.2	7.1
2	Cotton	20.1	6.7	31.1	48.8
3	Cereals	9.7	15.5	28.7	25.0
4	Fruit crops	7.6	10.3	25.0	3.6
5	Vegetables	6.0	2.9	4.8	4.8
6	Sugarcane	0.9	0.7	0.8	1.2
7	Pulses	0.3	0.0	8.2	9.6

In summary, micro-irrigation adoption in the two study locations led to (1) the prominence of high value and water intensive crops in the farming system, and (2) further improved the cropping intensity. This obviously will have implications for the sustainable use of groundwater resources.

Conclusions and implications

Economics of micro-irrigation systems

The study indicates that, for all of the crops considered, on average the use of micro-irrigation technologies resulted in a significant productivity and economic gain over the traditional surface irrigation methods. Moreover, the yield response to the conventional drip systems for banana and cotton was significantly superior to the low-cost drip systems, implying that the low-cost micro-irrigation technologies cannot be regarded as an end in themselves but as stepping stone for adopting the conventional systems, which are technically robust and economically more rewarding.

Determinants of micro-irrigation adoption

Technical and economic efficiency is but only one of the many variables that influence micro-irrigation adoption decisions of farmers. If technical and economic efficiency alone is the main determinant of adoption, micro-irrigation technologies would have dominated the traditional irrigation methods. The successful adoption of micro-irrigation requires, in addition to the technical and economic efficiency, two additional preconditions. These are: (1) the target beneficiaries need to be aware or knowledgeable about the technical and economic superiority of the technologies. This may be achieved through extension service in the form of demonstrations. Farmers own attributes such as level of education may also augment or complement the public extension services as educated farmers are active information seekers and experimenters, and (2) the technologies need to be accessible to the potential users. Awareness or knowledge does not guarantee actual adoption unless the technologies are made accessible to the farmers through devising institutional support system.

The most important variables influencing micro-irrigation adoption decisions in the present context were:

1. Years of schooling of the household head. As the level of education of the household head increases the likelihood of adopting micro-irrigation technologies increases. This confirms the fact that micro-irrigation technologies need special technical and managerial skills for proper utilization. Given the fact that the poorer section of the farming population tends to be less educated, special training program need to be instituted to enable poor people adopt and successfully manage micro-irrigation systems.
2. Access to groundwater. As expected ownership of wells significantly increases the probability of adoption of micro-irrigation technologies. Moreover, as the depth of wells and the horse power of pumps owned increase the likelihood of adopting micro-irrigation technologies increases. The well depth and horse power of pumps proxy the degree of water scarcity and the energy saving motives of the farmers.
3. Cropping pattern. The study indicates that the higher the share of cereals and pulses in the cropping pattern the lower the probability of adopting micro-irrigation technologies. This implies that farmers cultivating staple food crops are currently excluded from the benefits of innovations in micro-irrigation technologies.
4. Additional sources of income. As the share of income from other sources than farming (excluding wage labor income) increases, the probability of adopting micro-irrigation technologies increases. This shows the importance of cash in the initial adoption decisions of farmers.
5. Social and poverty status. Despite the technical transformation of micro-irrigation technologies to make them pro-poor, the well-to-do farmers still have significantly higher probability of adopting micro-irrigation technologies. In addition, farmers belonging to the high caste category have more chance of adopting micro-irrigation technologies.

Micro-irrigation technologies and poverty

The largest proportion of micro-irrigation adopters belong to the relatively wealthy group of farmers. This is especially so in Maharashtra. In Gujarat the situation is a bit milder, i.e., the adoption is not confined to the richest group but extends to the middle and rich farmers. However, in both locations the poor and the poorest section of the farming population have not benefited much from innovations in micro-irrigation adoption.

Thus, in light of this study, reducing the cost alone is not enough to improve the poverty outreach of micro-irrigation technologies. Three factors limited poor farmer's access to low-cost micro-irrigation technologies. First, the available low-cost micro-irrigation systems are suited to crops that are not popular among poor farmers. Poor farmers tend to allot a significant proportion of their area to staple food crops such as cereals and pulses. Secondly, their socioeconomic attributes (e.g., low level of education, being a member of low caste group, low poverty status, etc.) limit their access to information ultimately hindering their access to micro-irrigation technologies. Lastly, limited access to resources, specifically to groundwater in both quantitative and qualitative sense, hinders poor farmers from successfully adopting low-cost micro-irrigation technologies.

Micro-irrigation use and sustainable utilization of groundwater resources

The sustainability impact of micro-irrigation use depends upon: (1) the magnitude of the overall productivity gain following the shift from traditional method of irrigation to micro-irrigation system or the volume of water that is saved for use, (2) the behavior of adopters following the shift or the pattern of use of the saved water, and (3) the type and potential number of adopters.

The study indicates that the use of micro-irrigation technologies increases the marginal productivity of water. The improvement in the marginal productivity of water coupled with the effect of subsidy schemes that indirectly play the role of reducing the marginal cost or price of water, further increases the demand for irrigation water. Thus, a rational farmer continues to employ more water in the agricultural production process provided that she/he has no land limitation.

Specifically, the farmers are expected to respond in one or the other of the following ways depending on their prevailing circumstances. First, those already suffering from frequent crop failure or yield losses due to water shortage will make use of the saved water to obtain normal harvest or to minimize yield losses. Secondly, those irrigating only part of their potentially irrigable fields due to the inadequacy of water supply, will make use of the released water to increase irrigated area and hence reap more economic gain. Third, the high marginal productivity of water may spark the demand for more groundwater resources thereby increasing investments in groundwater development. The second and the third scenario may lead to groundwater overdraft, a fact reported by most of the sample farmers in Maharashtra. They claim that despite 15 years of experience with micro-irrigation, the groundwater level has substantially declined and the concentrations of wells have increased.

The other remarkable impact of micro-irrigation technologies with significant implications for the sustainable use of groundwater resources observed in the study locations has been the change in the cropping pattern, cropping intensity, and crop diversity. Micro-irrigation adoption led to the prominence of high value, water-intensive crops in the farming system, and further improved the cropping intensity through enabling the production of crops in the summer or Rabi. Thus, in the long run, the sustainability objective may conflict with poverty reduction and food security objectives unless proper regulatory mechanism is instituted.

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