RESEARCH
REPORT

93

Adoption and Impacts of Microirrigation Technologies

Empirical Results from Selected Localities of Maharashtra and Gujarat States of India

Regassa E. Namara, Bhawana Upadhyay and R. K. Nagar

International Water Management Institute

COMPREHENSIVE Assessment of water management in agriculture

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International Water Management Institute
P O Box 2075, Colombo, Sri Lanka

IWMI receives its principal funding from 58 governments, private foundations, and international and regional organizations known as the Consultative Group on International Agricultural Research (CGIAR). Support is also given by the Governments of Ghana, Pakistan, South Africa, Sri Lanka and Thailand.

The authors: Regassa E. Namara is an Economist of the International Water Management Institute (IWMI), Colombo, Sri Lanka (r.namara@cgiar.org) and Bhawana Upadhyay is an Associate Expert of IWMI at its office in Anand, Gujarat, India (b.upadhayay@cgiar.org). R. K. Nagar is a Development Economist and Management Consultant in Agribusiness and Rural Development in Anand, Gujarat, India (rknagar@icenet.net).

Acknowledgments: This study was supported by the Comprehensive Assessment of Water Management in Agriculture and IWMI-TATA Water Policy Programs.

The authors appreciate the cooperation extended by farmers who participated in the survey. We particularly thank Maria Saleth and R. Sakthivadivel for their reviews and invaluable comments, and David Molden, Tushaar Shah, Hugh Turral and Francois Molle for their comments on the earlier drafts of the paper. The authors also thank the research and development staff members of Jain Irrigation Systems Ltd. for their information on microirrigation issues in Jalgaon and in India in general.

Namara, R. E.; Upadhyay, B.; Nagar, R. K. 2005. *Adoption and impacts of microirrigation technologies: Empirical results from selected localities of Maharashtra and Gujarat states of India.* Research Report 93. Colombo, Sri Lanka: International Water Management Institute.

/ microirrigation / drip irrigation / sprinkler irrigation / irrigation systems / technology / models / economic analysis / yields / cropping systems / water conservation / food security / poverty / women / India /

ISSN 1026-0862
ISBN 92-9090-602-2

Cover photo by Mats Lannerstad shows an Alfalfa field irrigated by a microirrigation system in northern Gujarat, where dairying is the mainstay of the livelihood of the farming population, and a farmer irrigating his field using the conventional method.

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Acronyms

AKRSP	Aga Khan Rural Support Program
APPROTEC	Appropriate Technologies for Enterprise Creation
DAP	Diammonium phosphate
IDE	International Development Enterprises
MPP	Marginal Physical Product
NGO	Nongovernmental organization
SD	Standard Deviation
VMP	Value of Marginal Product

Glossary

Kharif	July-October crop season
panchayat	Institution of local self-governance in India, which is structured at district, block and village levels. A panchayat and its representatives have a uniform five-year term.
Rabi	November-April crop season
summer season	April/May-July crop season
taluka	A subdivision of a revenue district

Summary

Microirrigation technologies are aggressively promoted in India by the central government, state governments and many nongovernmental organizations (NGOs), both local and international, by providing different kinds of financial, institutional and technical support systems. These technologies are promoted primarily for one or more of the following reasons: (1) as a means to save water in irrigated agriculture, (2) as a strategy to increase income and reduce poverty, and (3) to enhance the food and nutritional security of rural households. Despite the reported significant economic advantages and the concerted support of the government and NGOs, the current microirrigation area in India remains an insignificant proportion of its potential. Based on the data from recent field studies in Maharashtra and Gujarat, this report analyzes: (1) the economics of alternative microirrigation technologies ranging from low-cost drip and sprinkler systems to the capital-intensive systems, (2) the determinants of adoption of microirrigation technology, (3) the poverty outreach of the different microirrigation systems, and (4) the sustainability implications of microirrigation adoption. In line with the findings of numerous other studies, this study indicates that microirrigation technologies result in a significant productivity improvement and, hence, economic gain over the traditional method of surface irrigation. It also shows that the productivity gain of conventional drip systems is significantly higher than that of low-cost drip systems. Thus, low-cost microirrigation systems cannot be regarded as ends in themselves but as stepping stones for adopting the conventional systems, which are technically robust and economically more rewarding. The most important determinants of microirrigation adoption include access to groundwater, the prevailing cropping pattern, level of education, financial resources, the social stratum of the household, and the wealth or poverty status of the farmer. Contrary to expectations, the majority of the current users of low-cost microirrigation systems belong to the richer section of the farming population. The study also indicates that the impact of microirrigation systems on the long-term sustainability of groundwater resources depends on the magnitude of the overall productivity gain following the shift from surface irrigation to microirrigation, the behavior of the adopters following the shift or 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 supply and competition between the various sectors of the economy for 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 scarce water resources. Microirrigation technologies constitute an element of such innovative intervention approaches. Originally, microirrigation 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 capital-intensive features to an input mode.

A survey of literature on the impacts of microirrigation technologies indicate that they are usually promoted primarily for one or more of the following objectives: (1) as a means of saving water in irrigated agriculture and averting the impending water crises (Narayanamoorthy 2003; Polak et al. 1997; Shah and Keller 2002), (2) as a strategy to increase income and reduce poverty among the rural poor, (3) to enhance the food and nutritional security of rural households (Bilgi 1999; Upadhyay 2003; Upadhyay 2004), and (4) as a means to extend the limited available water over a larger cropped area, especially during drought years or during the period before a monsoon season. Microirrigation technologies lead to poverty reduction through substantial increases in farm income due to an increased area of cultivation, better crop yields, enhanced output quality, early crop maturity and hence higher unit prices, and reduced cultivation costs, particularly for operations like irrigation and weeding. Microirrigation technologies enhance nutritional security by enabling the production and consumption of vegetables, particularly leafy vegetables, which are usually missing in the traditional staple diets of many cultures.

There are two lines of thought regarding the water-saving potential of microirrigation technologies. The first line of argument is that the adoption of microirrigation technologies results in net water savings, thereby easing the prevailing water-scarcity problems. The water saving is attained through substantial reduction in losses due to evaporation and inefficient field conveyance and distribution systems.[1] For instance, water application can be reduced by 50 to 100 percent through the drip method of irrigation. This is the declared motive for the state governments of India to embark on the massive popularization of these technologies. However, the

[1]For more information on this see Sivanappan 1994 quoted in Narayanmoorthy 1997.

farmers' rationale for adopting these technologies may be different from the policy objectives of the state governments. Farmers may give more weight to the other attributes of microirrigation technologies such as improvements in yield, reduction in labor requirement, improvement in output quality, etc. in their adoption decisions.

The second line of thought is that even though microirrigation 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 aggregation such as the watershed or the basin (Molden et al. 2003). According to this line of thought, 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 as useful. Thus the adoption of microirrigation technologies may not automatically lead to water savings at the basin level unless enabling institutional and economic policy instruments are put in place that allow the equitable distribution or allocation of the saved water.

Various studies in India have shown a considerable return to farmers' investments in microirrigation technologies (Dhawan 2002; Narayanamoorthy 1997; Narayanamoorthy 2003; Verma et al. 2004). For instance, Narayanamoorthy reported an increase in farm business income of 64.6 percent, 79.5 percent and 83.4 percent for banana, grape and sugarcane, respectively for drip irrigation adopters in the Maharashtra state of India. Substantial efforts have been made to disseminate and popularize these technologies. For instance, state governments of India have encouraged private involvement in the manufacturing and distribution of the technologies and adoption by farmers through targeted subsidy schemes. Despite these efforts, however, the area under current microirrigation systems remains an insignificant proportion of the potential. Thus, finding out why microirrigation technologies are not disseminating fast and to the extent anticipated is an important research issue.

Objectives

This report presents the results of a study done to assess the adoption and impacts of microirrigation technologies in selected villages of Maharashtra and Gujarat states of India. Data were collected in two phases. First, focus group interviews and key informant surveys were undertaken. Second, relevant household, farm and field level data were gathered through structured questionnaire surveys.

The specific objectives of the study were to:

1. Analyze the economics of alternative microirrigation technologies ranging from low-cost drip and sprinkler systems to capital-intensive systems.
2. Identify the determinants of microirrigation adoption and assess their quantitative impacts.
3. Evaluate the poverty outreach of the different microirrigation technologies.
4. Discuss other impacts of microirrigation adoption.

Background

Study Locations

The study was conducted in the Rajkot and Junagadh districts of the Gujarat state (figure 1) and in the Jalgaon district of the Maharashtra state of India (figure 2). The salient features of the study locations, including the list of the study villages, are given in Appendix 1.

FIGURE 1.
The study districts (and talukas) of Gujarat state.

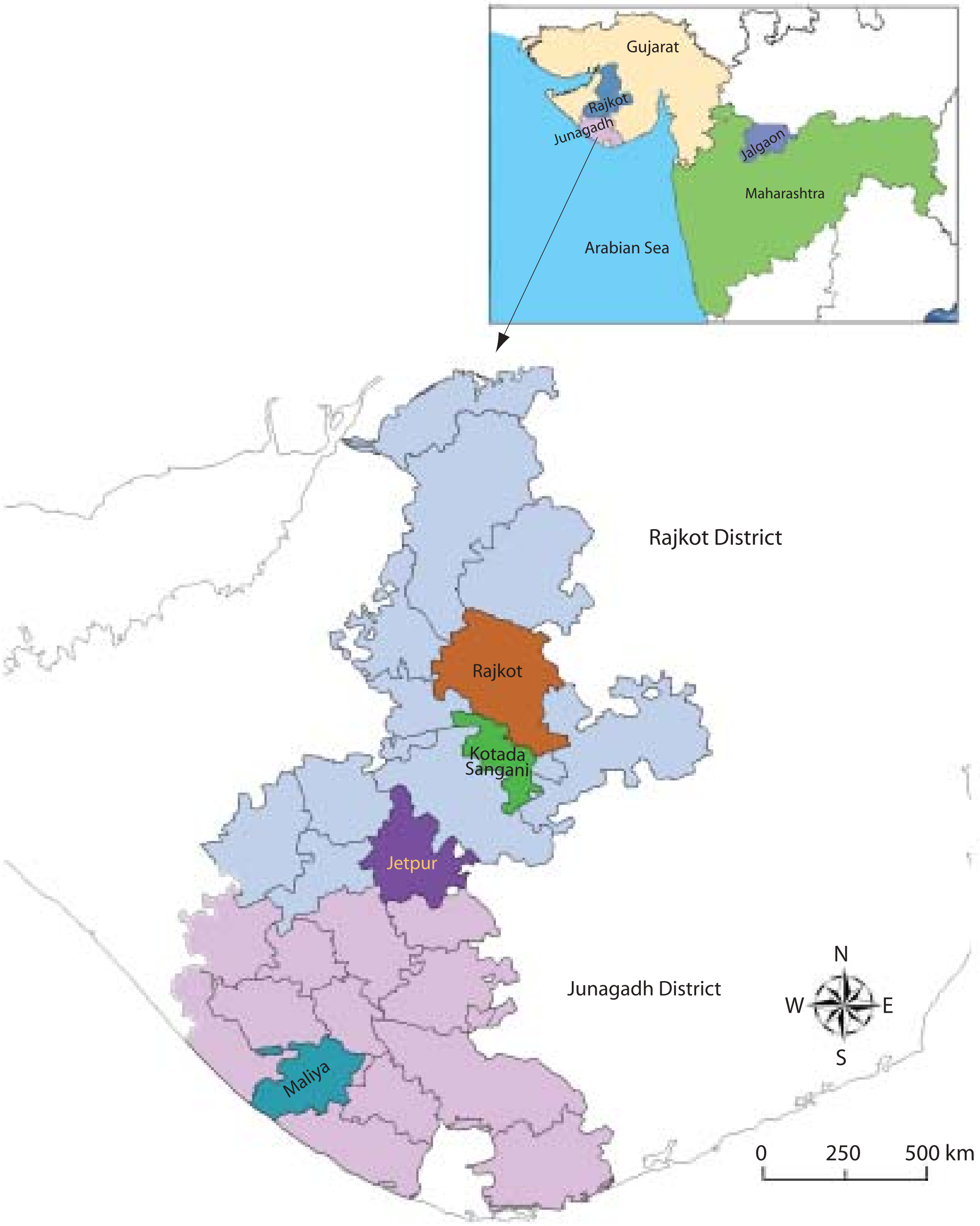
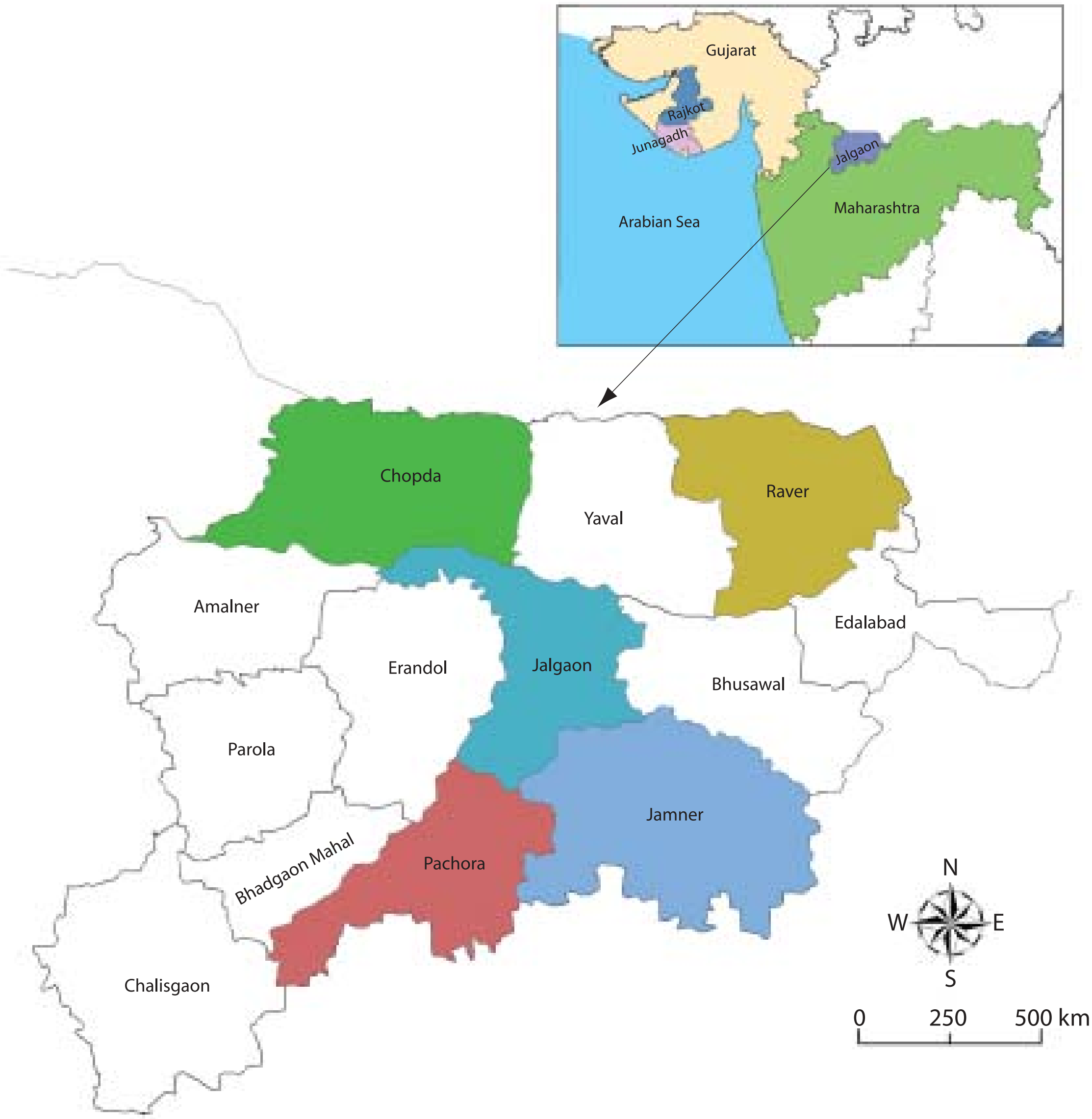


FIGURE 2.
The Jalgaon district of Maharahstra showing the five talukas in which the study villages are located.



In Jalgaon district, 14 villages in five talukas were sampled from a total of 1,510 villages spread over 13 talukas in the district (see Appendix 1, table A1). The average annual rainfall in the district is 747.7 mm, of which 87 percent occurs during the monsoon months of June-September. The highest rainfall occurs during July. The total perennial river length in the district is 730 km.

In Junagadh district, 6 villages from the Maliya taluka were selected for the study. In this district, out of 1,034 inhabited villages, 966 are electrified. Moreover, all the villages have access to drinking water in wells or rivers or to pipe-borne water. And public transport is available in 90 percent of the villages. Similarly, in Rajkot district, progress in rural electrification is remarkable with 854 out of 856 inhabited villages having access to electricity. All the villages have access to drinking water in wells or canals or to pipe-borne water. However, wells are the main source of drinking water. Public transport is available in 97.4 percent of villages. All the villages of the Kotada Sangani and Jetpur talukas have public transportation.

The proportion of the rural population is higher in Junagadh and Jalgaon districts. The population density for the study districts varies from 200 to 316 people per km^2 and Jalgaon was the most densely populated district in 2001 with 316 people per km^2 (see Appendix 1, table A2).

In all the study districts, the gross crop area has increased over the years from 1992 to 2001. The percentage of cultivated area ranges from 47 to 74 percent with Jalgaon recording the highest cultivated area. The cropping patterns of the study locations during the 1991/92 seasons are given in Appendix 1, table A3. There are important differences in the cropping pattern among the three districts and between the two states. Oil crops, specifically groundnuts, are the most important crops in Rajkot and Junagadh districts, while in Jalgaon cereals followed by cotton are the most important crops. Fruit crop production (especially banana) is significant in Jalgaon. The banana cultivated area in Jalgaon alone constitutes over half of the total banana area in Maharashtra state. Fruit crop production is relatively insignificant in the other two study districts.

A comparison of cropping patterns of the two states shows that cereals, pulses and fiber crops, in that order of significance, are the important crops in Maharashtra. Cereals, oil crops, fodder crops, and fiber crops, in that order of significance, are the most important crops in Gujarat. The significance of fodder crops in Gujarat is an indication of the importance of the livestock (dairy) sector in the farming system. Livestock occupies a pivotal place in the rural economy of Junagadh and Rajkot districts, with cows and buffaloes making up the highest percentage of livestock. Milk dairies and cooperatives thus contribute significantly to the economy of these regions. Moreover, the fishing industry supports many households in the coastal areas of Junagadh.

The percentaged irrigated area for the study districts ranges from 16 to 26 percent and the lowest irrigated area is observed in Jalgaon. When the two states are compared, the percentage of irrigated land is higher in Gujarat than in Maharashtra. Except in Rajkot, the total area under irrigation has shown an upward trend during 1992 to 2001. In Rajkot, the total irrigated area has decreased slightly due to a sharp decline in well irrigation. In fact the two study districts in Gujarat are counted among the five districts of Gujarat that have recorded a decline in water level. During 1982-2001, all the study districts experienced a decrease in water level of more than 4 meters. Furthermore, during 1999-2002, 5 districts of Gujarat and 27 of Maharashtra recorded a decline in water level. Along with the observed decline in water level and abandonment of some wells, there is well drilling activity. As of November 2000, the number of wells drilled in Gujarat and Maharashtra were 579 and 693, respectively.

Institutional Support Systems for Microirrigation Technology Dissemination

A number of NGOs, governmental organizations and private business firms are engaged in the promotion of microirrigation technologies in the study locations. The most prominent NGOs operating in the region are the Aga Khan Rural Support Program (AKRSP) in Gujarat and International Development Enterprises (IDE) in both Maharashtra and Gujarat. IDE's work is focused mainly on designing or redesigning microirrigation technologies to make them more poor-friendly and creating awareness among farmers about the new designs through promotional activities like meetings with farmers, video shows, field demonstrations, exhibitions in village markets and so on. IDE does not subsidize the financial investment for acquiring the technology. They may, however, connect the farmers to financial institutions.

A number of private firms are engaged in manufacturing, marketing and distributing microirrigation systems. All in all, there are over

75 companies in India manufacturing and selling drip irrigation systems.[2] The clients for these firms are primarily the highly commercialized large farmers, specializing in cash crop production. However, intense competition has driven new attempts to customize irrigation technology to suit the budget constraints of the small farmer in an effort to expand market outreach.

Among these firms, Jain Irrigation Systems is well known among the farmers of Jalgaon. The special feature about this firm is that it is a homegrown company while the others are subsidiaries of foreign companies, mainly from Israel. Jain Irrigation Systems provides comprehensive services, including engineering (manufacturing), assembling, marketing or distribution, research and farmer training. The research component includes soil analysis and production of tissue culture of banana rhizomes. In addition to irrigation systems, the company also provides input and output marketing services. They distribute improved seeds or planting materials, fertilizers and pesticides and buy farm output from farmers. They are also engaged in the processing and export markets. Jain Irrigation Systems' managers claim that Jalgaon is the most arid area in which banana cultivation has been made possible through innovation in microirrigation.

Private firms and NGOs have their own elaborate marketing systems and channels. In any case, the main participants in the supply chain include manufactures, dealers, distributors, assemblers, extension volunteers and farmers. These market participants operate at different spatial scales ranging from village to taluka or district. The NGOs and government institutions facilitate market efficiency through provision of information and subsidies. A typical microirrigation-marketing channel in Gujarat where AKRSP is involved is depicted in table1.

AKRSP recruits and trains Assemblers and Village Extension Volunteers. The purpose of the Village Extension Volunteer is the dissemination of information and identification of farmers interested in trying the technology. The Assembler prepares a proposal based on the feedback from a Volunteer to send to AKRSP for approval. The AKRSP approves the proposal based on an assessment by AKRSP's own technical staff. The Assembler then obtains the equipment and parts direct from the dealer and installs the system in the farmer's field. Following successful installation, the subsidy is released direct to the farmer. Although this is the normal channel, in many cases, the farmer may deal either directly with the Assembler or with AKRSP.

The subsidy given to farmers depends on the type of the institutions involved in promotion. AKRSP has two subsidy schemes depending on the quality of water used for agriculture. For farmers operating in saline areas, the subsidy rate is 50 percent of the cost while the corresponding figure for sweet water areas is 33 percent. The Government of Gujarat, in its scheme for better use of water in irrigation, has authorized different subsidy rates depending on

TABLE 1.
An example of a microirrigation technology supply chain in AKRSP-assisted areas.

Channel 1	AKRSP	Farmer		
Channel 2	Assembler	Farmer		
Channel 3	Assembler	AKRSP	Farmer	
Channel 4	Dealer/Supplier	Assembler	Extension Volunteer	Farmer

Note: AKRSP = Aga Khan Rural Support Program.

[2]Some of these are: Netafim Irrigation India Pvt. Ltd., Finolex group, Plastro Plasson Industries India Ltd., Plastro Irrigation India Ltd., Balson Polyplast Pvt. Ltd., Naan Irrigation System, Pragati Microirrigation System, Jain Irrigation Systems, and Ganesh Irrigation.

the socioeconomic status of the farmer and the model of microirrigation technology. For small, marginal, backward, tribal and female farmers, a 50 percent subsidy is provided for procuring drip, sprinkler and pipeline systems. Large farmers and recognized social and educational institutions linked to agriculture get a 35 percent subsidy for drip systems, 33 percent for sprinklers and 40 percent for pipelines.

Since 2002, the Government of Gujarat has set more restrictive preconditions regarding eligibility for subsidy incentives. According to a new directive, a subsidy is given for a continuous block of 5 villages or a block of 100 hectares. In other words, a group of 50 beneficiaries have to be formed to apply for a subsidy. The intention of the new approach is to ensure that sufficient demonstration of trust in the technology develops to encourage an early spread of the technology. However, this approach has changed the adoption pattern from an individual decision-making process to a collective one. Similarly, the Government of Maharashtra was earlier providing a 50 percent subsidy for microirrigation adoption for up to 2 hectares of land per farm. This scheme was withdrawn in 2002 but was reintroduced at a 25 percent rate in October 2003. Following the withdrawal of the subsidy scheme, some of the microirrigation suppliers, such as Jain Irrigation Systems, experienced a sharp decline in sales.

In addition to the state government subsidy schemes, there are also central programs for the promotion of microirrigation technologies. Under India’s last Five-Year Plan, the subsidy was set at 25 percent for all categories of farmers, down from the previous 50 percent rate. The central programs are commodity-based. Among these, the central scheme for the use of plastics in agriculture (horticultural development) provides a 25 percent subsidy for all forms of microirrigation technology. Likewise, the central subsidy scheme for the integrated development of vegetables, including root and tuber crops, provides an incentive of a 25 percent subsidy.

Many farmers consider the subsidy procedure as a very cumbersome undertaking. For example, a farmer has to first approach a dealer and pay the full cost of the system to the dealer to get the drip system installed. Only after installation can a farmer make an application for a subsidy to the district panchayat along with the required documents like proof of installation and land ownership. An officer from the panchayat recommends and sends the proposal to a deputy director only after inspecting the field to confirm the installation of the system. Finally, the relevant deputy director approves the subsidy and a check is sent directly to the farmer. This procedure is seen as a complicated one by many farmers as they have experienced difficulty in meeting the initial expenses to buy the system. The farmers complain that the subsidy is not being provided at the time when it is most needed. Thus the significance of the subsidy scheme to the cash-constrained, poor farmers is particularly limited.

Microirrigation Systems and their Technical and Socioeconomic Attributes

Different kinds of traditional surface irrigation and microirrigation systems are found in the study villages (table 2). Among the surface irrigation methods, flooding is most common in the sample villages of Gujarat while the furrow system is more prevalent in the Maharashtra samples. Few fields are under rain-fed farming. Thus, the proportion of area under irrigated farming in the sampled villages is way above the average levels for the study districts and the two states. The proportion of rain-fed fields is higher in Maharashtra than in Gujarat, including fields of crops such as maize, sorghum, pulses and oil seeds. Microirrigation technologies can be categorized into two groups based on their technical, economic and social attributes. These are low-cost microirrigation technologies and the commercialized, state-of-the-art microirrigation systems. The low-cost microirrigation technologies include the “pepsee,” easy drip, various kinds affordable microirrigation systems designed by IDE, microsprinklers and microtube

TABLE 2.
Types of irrigation systems observed in the study locations.

Irrigation system	Maharashtra		Gujarat	
	Area (ha)	%	Area (ha)	%
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
Microirrigation systems				
Pepsee or easy drip (AMIT)	16.6	2.6	27.0	3.4
Microsprinklers	0.0	0.0	90.2	11.0
Microtube 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	

Note: AMIT = IDE's Affordable Microirrigation Technologies

drip systems. The latter class of microirrigation technology includes conventional drip and sprinkler systems.

The lack of adopters of conventional sprinkler and microsprinkler irrigation systems among our sample farmers from Maharashtra does not mean that these technologies are totally absent in the state. There are other villages in Maharahstra where sprinklers are in use.

The technical, economic and social attributes that distinguish low-cost microirrigation systems from commercial, state-of-the-art microirrigation systems are as follows.

1. *Affordability*: The dominant feature of the low-cost microirrigation systems is that they require little initial capital for successful adoption, which has a high opportunity cost in the context of the study locations. The reduction in capital intensity was realized through the replacement of conventional emitters with microtubes, using a clean piece of cloth in place of the filter, removing the nutrient-tank components and valves, and replacing the pipe and lateral network of conventional irrigation systems by a network of low-cost tubes.
2. *Local manufacturing capacity*: The systems are designed with the best available components, with preference given to local manufacturing that only requires relatively unsophisticated facilities, but not at the expense of affordability and functionality.
3. *Payback period:* The income generation potential of the systems (compared to the systems they replace) at least covers the investment cost in one irrigation season.
4. *Compatibility with the farming system*: The systems are compatible with smallholder farming systems because they are available in a range of small packages from as little as 20 square meters to a couple of hectares. They are also expandable, so the area served can be enlarged as farmers gain confidence in the technology and become more financially capable.
5. *Pressure requirement*: The required inlet pressure head for the low-cost drip systems ranges from 1 to 4 meters, while the conventional systems require high pressure, careful filtration and special acid treatment to keep it operating properly.

6. *Ease of technical understanding by users*: The systems are simple and easily understood, and operated and maintained by average users, while the conventional systems are sophisticated and need technical expertise.

7. *Uniformity of irrigation application*: Less uniformity as compared to the state-of-the-art microirrigation systems.

8. *Operational convenience*: The low-cost microirrigation technologies have low operational convenience compared to conventional systems. For instance, installing low-cost drip systems requires higher labor input.

9. *Compatibility with local micro-entrepreneurship*: The skills required for assemblage and servicing of the systems are not high and are compatible with those of local micro-enterprises. The design, service and maintenance costs are also low.

The successful adoption of microirrigation technologies requires the fulfillment of 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 potential users.

Data and Analytical Methods

The data for this study were gathered through a survey of 448 farm households selected at random in Gujarat and Maharashtra, during September and October 2003. A structured questionnaire survey was preceded by focus group discussions and key informant surveys in the study locations. The following analytical approaches were used to analyze and interpret the resulting data.

Logit Adoption Model

To facilitate the choice of an appropriate econometric model for analyzing the determinants of microirrigation adoption and their quantitative significance, a precise definition of microirrigation adoption or adopter is required. In the present context, microirrigation adopters are those farmers who use one or more of the microirrigation technologies being promoted at the time of the study by the government or NGOs on all or part of their fields. In this case, the microirrigation adoption variable is a discrete-dichotomous variable (a farmer is either a microirrigation adopter or a non-adopter). Thus the definition includes partial adopters. The non-adopters, or non-microirrigation farmers, are those who have not used microirrigation during the year of the survey.

In 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. 1985). Here the *logit* model is used to explain the microirrigation adoption process.[3] The specification of the *logit* model is as follows:

$$P_i = probability\ (F_i = 1) = \frac{\exp(z)}{1 + \exp(z)} \qquad (1)$$

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

where P_i denotes the probability that the i^{th} farmer has adopted microirrigation technology (F_i = 1) and

$$Z = \beta_0 + \sum_{i}^{m} \beta_i X_i \qquad (2)$$

where β_0 is the intercept, β_i is a slope parameter in the model, and X_i is an independent variable. In the *logit* model, like in any nonlinear regression model, the parameters are not necessarily the marginal effects (Greene 2000; Kennedy 2001). They rather represent changes in the natural log of odds ratio for a unit change in the explanatory variables.[4] The marginal effect (or the quantitative importance of the explanatory variables) for the logit model is expressed as follows:

$$\delta P_i / \delta X_j = \frac{\exp(z)}{1+\exp(z)} \left(\frac{1}{1+\exp(z)} \right) \hat{\beta}_j \qquad (3)$$

Description of the Hypothesized Microirrigation Adoption Variables

As a prelude to the analyses of the logit model results, let us first discuss the explanatory variables included in the model. The most common variables used in modeling technology adoption processes are human-capital variables (e.g., level of education and 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. 1985; Rogers 1995; Legans 1979; Buttel et al. 1990).

In the present case, the variables hypothesized to influence microirrigation adoption decisions are summarized in table 3. The variables were selected based on literature reviews of the determinants of microirrigation adoption (Caswell 1999; Shrestha and Gopalakrishnan 1993; Sakks 2001), the researchers' own perceptions of the socioeconomic setting of the study locations, and the technical attributes of the microirrigation systems prevalent in the study locations. These variables may be conveniently classified into:

1. *Family size and demographic structure*: This group of variables includes the 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 and level of education of the household head*: The variable age may be a surrogate for many other socioeconomic variables including experience or skill, wealth and conservatism. The effect of this variable on microirrigation adoption decisions depends on which of these age dimensions dominates. The level of education augments extension services and is hypothesized to positively contribute to the microirrigation adoption probability.
3. *Ownership of agro-wells and pumps and their technical attributes*: The propensity of agro-well owners to adopt microirrigation systems is expected to be higher than that of surface water irrigators mainly due to differences in the type of property rights associated with the two modes of irrigation. Whereas surface

[4]After a few steps of transformation , equations 1 and 2 may be simplified as follows:

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

Here β_i is interpreted as a change in the log of odds associated with a one-unit change in an explanatory variable.

TABLE 3.
Description of variables included in the logit regression model.

Variable		Maharashtra				Gujarat			
		Adopters		Non-adopters		Adopters		Non-adopters	
	Unit	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	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 household head	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	Foot	63.9	59.3	19.2	36.2	75.6	56.0	62.6	42.7
Access to groundwater	Percentage	96.3	-	52.5	-	100	-	93.0	-
Power of the pump owned	Horsepower	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 income	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

Note: SD = standard deviation.

water sources are owned publicly or communally, groundwater sources are usually owned privately. Thus the water supply from groundwater sources is more reliable and flexible than that from surface water sources. Hence, ceteris paribus, agro-well owners have the motivation or incentive to use the available water as efficiently as possible through employing various mechanisms such as microirrigation systems. The technical characteristics of agro-wells (e.g., depth) and pumps (horsepower) impinge on the owners' decision to adopt microirrigation technologies due to implications for energy cost or the scarcity of well water.

4. *Cropping pattern or the farming system*: This group of variables is represented by the shares 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 microirrigation adoption decisions is expected to be substantial because of the crop specificity of the available microirrigation 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 principal component analysis, and the share of income from off-farm and non-farm activities. Ceteris paribus, high caste households are expected to have a higher probability of adopting microirrigation technologies. Similarly, farmers with a higher poverty index value (wealthier farmers) have a higher likelihood of being microirrigation technology adopters. The share of the non-farm and off-farm income variable is also hypothesized to increase the probability of adopting the technologies through the availability of additional cash for procuring microirrigation technologies, which are normally considered as capital-intensive.

Transcendental Production Function

For the data generated through experimentation or controlled trials, marginal analysis based on partial farm budgets is the most common approach used in assessing the economic advantage of new technologies (CIMMYT 1988). This is because, in controlled trials, one or two treatments are varied at a finite number of fixed levels. In the case of survey data, however, all levels of input vary continuously and hence it is difficult to estimate incremental gains and costs at discrete points where input levels change. In this case, continuous analysis is used to evaluate the technical and economic efficiency of the different microirrigation technologies. Specifically, we fitted a transcendental production function to the data to estimate marginal productivities and measure the important interactions among the various yield-influencing factors.

The transcendental production function is an extension of the well-known Cobb-Douglas production function and represents the neoclassical three-stage production process.[5] It can be viewed as a generalization of the Cobb-Douglas production function that can depict the three stages of production and has variable production elasticity and may be specified as follows:

$$Y = AX_1^{\alpha_1} X_2^{\alpha_2} X_3^{\alpha_3} \ldots X_n^{\alpha_n} e^{(\gamma_1 X_1 + \gamma_2 X_2 + \gamma_3 X_3 \ldots \gamma_n X_n + d_1 D_1 + d_2 D_2 + \ldots d_l D_l + \gamma_{12} X_1 X_2 + \ldots \gamma_{ij} X_i X_j)} \qquad (4)$$

[5]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 are at a fixed proportion to each other (see Debertin 1986).

where, X represents an agronomic and irrigation water input (continuous variables). These inputs are weeding cost (man-days/ha or Rs/ha), seed cost (Rs/ha), pesticide (l/ha), irrigation water pumping (hr/ha), nitrogen (kg/ha), phosphorus (kg/ha) and potassium (kg/ha). And D is a dummy variable representing the different microirrigation technologies, namely, conventional drip systems, microtube drip systems, low-cost drip systems, microsprinklers and conventional sprinklers.

The transcendental production function specified in equation 4 can easily be transformed to natural logs to yield

$$\ln Y = \ln A + \sum \alpha_i \ln X_i + \sum_i + \gamma_i X_i + \sum_i \sum_j \gamma_{ij} X_i X_j + \sum_l d_l D_l \qquad (5)$$

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_j is a measure of the effect of dummy variables or measures the deviation of the mean effect of dummy variable D_l (the different kinds of microirrigation 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:

$$\delta Y / \delta X_i = MPP_i \geq 0 \qquad (6)$$

where, MPP_i is the Marginal Physical Product of input *i*.

The point beyond which output starts to decrease with additional units of X_i ($MPP_i < 0$) 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:

$$\pi = P.Y(X) - x'C \qquad (7)$$

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

$$P.(\delta Y / \delta X_i) = P.MPP = VMP_i = C_i \qquad (8)$$

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 (C_i).

Principal Component Analysis

One of the hypotheses about microirrigation technologies is that their adoption among poor farmers is inhibited by the high initial capital requirement.[6] However, there is little information regarding the adoption patterns of the different makes and modes of microirrigation technologies among the potential adopters differentiated by poverty status. Specifically, it is necessary to see whether the poorest section of the farming community is the prime beneficiary of the low-cost microirrigation systems as originally envisaged. These issues were investigated by: (1) analyzing the relative poverty status of the adopting and non-adopting farmers using what is known as an indicator-based poverty assessment tool (see Henry et al. 2003 and Namara et al. 2003), (2) grouping the farmers into five

[6]It was in response to this that NGOs such as IDE and Appropriate Technologies for Enterprise Creation (APPROTEC) have introduced low-cost alternatives to the conventional capital-intensive ones.

poverty strata (i.e., very poor, poor, middle, rich and very rich), and (3) analyzing the pattern of distribution of the adopters of different kinds of microirrigation technologies across the five identified poverty strata.

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 principal component analysis.

Analyses of Microirrigation Adoption

Dynamics of Microirrigation Adoption

There is a marked difference in the temporal adoption pattern of microirrigation technologies between Maharashtra and Gujarat. The Maharashtra farmers in the sample were aware of the technologies since the early 1980s, while in Gujarat farmers knew about the technologies only since the early 1990s (figure 3). However, the peak period of adoption occurred within the last 5 or 6 years in both states (figure 4). In both locations, about 90 percent of the non-adopters are aware of microirrigation technologies.

In Gujarat, there is a contrast regarding the information source of microirrigation between adopters and non-adopters (table 4). The current microirrigation adopters initially learned about it from diverse sources including NGOs, other farmers and public extension systems, in that order of importance. The non-adopters had a relatively limited range of sources of information

FIGURE 3.
Year of first-time awareness among farmers about microirrigation technologies.

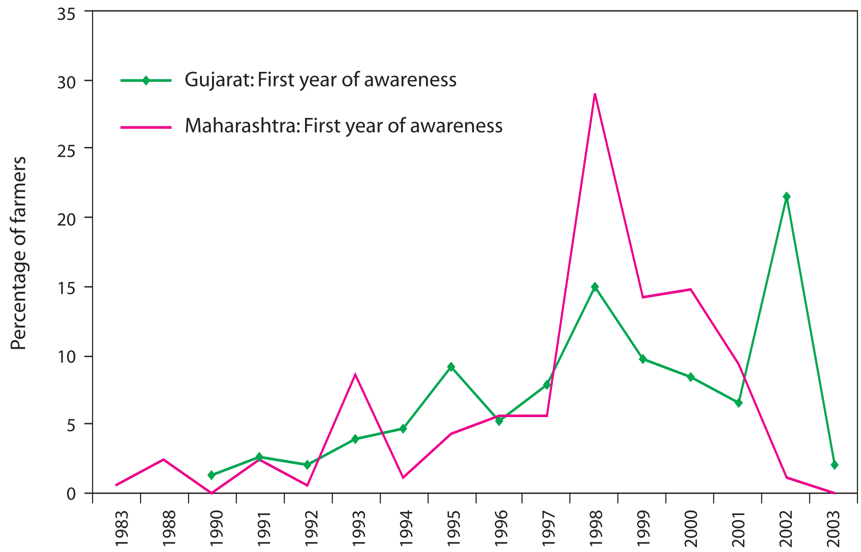
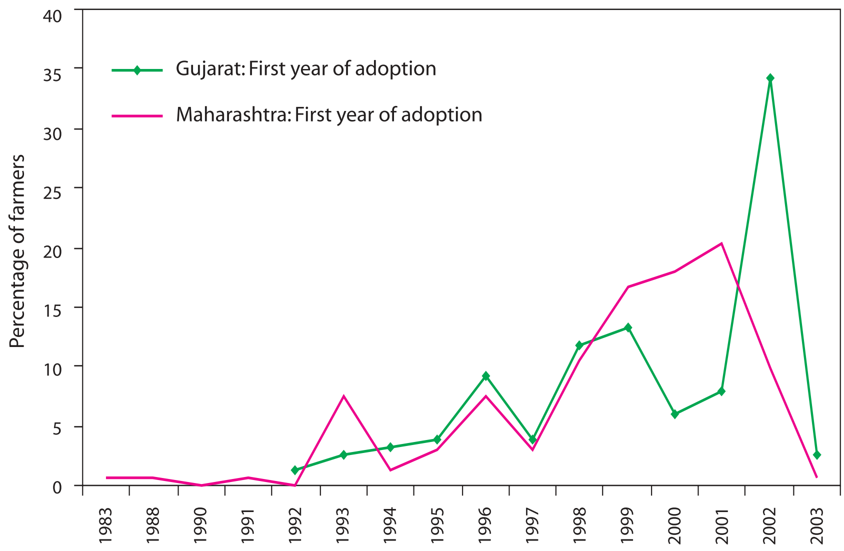


FIGURE 4.
Year of first practical use of microirrigation technologies.



and a significant proportion of them heard about microirrigation technologies from other farmers either by word of mouth or through field observation. In Maharashtra, there is no significant difference between adopters and non-adopters regarding the information source for microirrigation. Both categories became aware of the technologies from other farmers. This may be due to the fact that in this area the technology had already taken root.

TABLE 4.
Sources of information for microirrigation dissemination.

No.	Source	Gujarat		Maharashtra	
		Adopters (%)	Non-adopters (%)	Adopters (%)	Non-adopters (%)
1	NGOs	35.3	33.3	0.0	0.0
2	Other farmers	26.1	43.9	84.7	85.8
3	Dealers	7.8	4.5	0.0	0.0
4	Cooperatives	5.2	6.1	0.0	0.0
5	Government/public extension	11.1	1.5	0.0	2.9
6	Company/manufacturer	5.2	0.0	9.8	0.0
7	Private business people	3.9	0.0	0.0	0.0
8	Village agrifair	1.3	0.0	0.0	0.0
9	Banks	0.7	0.0	0.0	0.0
10	Agents	1.3	0.0	1.3	0.0
11	Newspapers and TV	0.0	1.5	0.0	0.0
N		152	60	156	35

The farmers in Gujarat noted about 19 advantages of microirrigation technologies while those in Mharashtra mentioned 15 advantages (table 5). These show that the adoption of microirrigation technologies has complex physical, biological and social ramifications. In both locations water and power savings were consistently mentioned by the majority of the farmers as the most important merits of microirrigation technologies.

In Maharashtra, about 97.5 percent of the farmers who are currently using microirrigation technologies have indicated that they will continue using the technologies. The corresponding figure for Gujarat is 96.7 percent. A few farmers from both states intend to discontinue the use of microirrigation technologies. The main reasons given for discontinuance are summarized in table 6. Some farmers also claimed that there was no substantial benefit from microirrigation technology adoption or that the flooding method did give better results. Frequent rodent damage and lack of suitable land (i.e., infertile and stony fields) are some of the other adoption constraining factors.

Similarly, the farmers who intend to continue using microirrigation technologies were asked whether they planned to increase the area under microirrigation. About 80 percent of the farmers in Gujarat and 30.8 percent in Maharashtra responded that they would like to put more land under microirrigation. The farmers who were not willing to increase the area under microirrigation gave the following reasons: (1) shortage of land, (2) water shortage, (3) microirrigation systems are not durable, (4) limited capacity of the pumps they own, (5) salinity problems, specifically in Gujarat, (6) insufficient subsidy (reduced from an

TABLE 5.
Perceived advantages of microirrigation technologies.

No.	Advantage	Gujarat farmers (%)	Maharashtra farmers (%)
1	Saves water	96.1	98.8
2	Saves power	65.4	96.9
3	Reduces disease incidence	60.0	0.0
4	Higher yield per unit area	35.9	0.6
5	Convenient irrigation timing	28.1	77.3
6	Reduces labor costs	25.5	21.5
7	Allows irrigated area expansion	24.8	4.9
8	Improves quality of produce	24.2	6.7
9	Extends irrigation time	23.5	41.7
10	Even distribution of water in the field	23.5	25.4
11	Allows pre-monsoon planting	20.9	3.1
12	Reduces weed growth	20.9	0.0
13	Reduces crop failure	18.3	0.0
14	Can work on undulating fields	18.3	4.9
15	Reduces soil erosion	13.1	0.0
16	Enables crop production in summer	12.4	6.1
17	Allows efficiency in manure use	11.1	1.8
18	Allows efficiency in fertilizer use	9.8	2.5
19	Reduces insect damage	1.3	2.5
N		153	156

TABLE 6.
Perceived disadvantages of microirrigation adoption.

No.	Disadvantage	Gujarat farmers (%)	Maharashtra farmers (%)
1	High initial capital requirement	40.5	1.8
2	Clogging problems	36.6	0.0
3	Maintenance problems	30.7	3.1
4	Difficult to install	25.5	3.1
5	Requires know-how and skills	18.3	0.6
6	Crop specificity	16.3	0.0
7	Limits crop diversification	14.4	0.0
8	Interferes with harvesting	11.8	0.0
9	Increases labor demand	7.2	0.0
10	Interference with agronomic practices	5.9	0.0
11	Tail-end plants get less water	4.6	0.0
12	Cumbersome procurement process	3.9	0.0
N		153	163

initial 66 percent to 25 percent), (7) lack of suitable microirrigation technology, and (8) maintenance difficulties.

Factors Influencing the Adoption of Microirrigation Technologies

Having probed into the mechanics of the hypothesized relationships between the dependent and explanatory variables, we now turn to the analyses of the results of the logit adoption model (table 7). Most of the variables included in the model had the expected signs. 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 indicate the status of labor availability in the household, had an insignificant effect reflecting the lower labor requirement of microirrigation technologies as compared to the traditional irrigation methods.

The human-capital variables are of special interest in relation to the microirrigation 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 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 might be because the age variable may have captured more the experience and wealth aspects than its conservatism dimension. The interaction between education and age had the expected sign, but was statistically significant only in Gujarat. The reason for the insignificance of these variables in Maharashtra may be that microirrigation systems have a long history and are no more considered as new technologies in this area. In other words, microirrigation technologies are used by most farmers. The negative sign for the years of schooling-by-age interaction effect could be understood from the commonly observed negative correlation between the age and level of education. In other words, younger farmers tend to be more educated than their older counterparts.

As we anticipated, the ownership of dug wells and bore wells had a strong effect on the probability of adoption of microirrigation technologies in both states. This is because well

TABLE 7.
Factors influencing the adoption of microirrigation technologies.

Variable	*Gujarat*			*Maharashtra*		
	Coefficient	t-ratio	Marginal effect	Coefficient	t-ratio	Marginal effect
Constant	-6.370	-1.748[a]	-0.99841	-7.0481	-2.408[b]	-0.4367
Family size	0.2079	1.176	0.03258	0.2701	1.266	0.01673
Age of household head	-0.00009	-0.004	-0.00001	0.0438	1.164	0.00271
Years of schooling of household head	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[b]	0.16373	1.1903	2.420[b]	0.07375
Dependency ratio	-0.00045	-0.035	-0.00007	-0.0109	-0.846	-0.00068
Poverty index	0.5569	2.366[b]	0.08728	0.5385	1.600[a]	0.03337
Access to groundwater	3.1345	1.101	0.49126	4.4406	3.707[c]	0.27514
Depth of well	0.0020	0.459	0.00031	0.0068	1.034	0.00042
Horsepower of pump	0.5342	5.590[c]	0.08372	0.3258	2.722[c]	0.02019
Share of cereals and pulses	-0.0545	-1.761[a]	-0.00855	-0.0156	-0.943	-0.00097
Share of fruit crops	0.00320	0.144	0.000501	0.05075	2.232[b]	0.03145
Share of vegetables	0.0565	2.027[b]	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[a]	0.00367
Share of off-farm and non-farm income	-0.02189	-0.415	-0.00343	0.08905	2.598[c]	0.05518
Square of share of off-farm and non-farm income	0.00060	0.537	0.000094	-0.00192	-3.024[c]	-0.00012
Loglikelihood function		-82.79477			-63.22107	
χ^2 (d.f.)		114.2133(17)[c]			135.2486(17)[c]	
Percentage of correct predictions		83.9			86.1	

[a] Significant at 10% [b] Significant at 5% [c] Significant at 1%

owners have a high degree of control over the water source and have the motivation to efficiently use the water available in the well. Moreover, the depth of well (in Gujarat) and the horsepower of the pump owned (in Maharashtra) had a significant positive impact on the likelihood of adopting these technologies. This indicates that as the wells get deeper, the farmers are obliged to spend more money for pumping. Therefore, the higher adoption probability among farmers owning deeper wells and higher horsepower pumps partly reflect the farmers' power-saving motives.

Contrasting results were found for Maharashtra and Gujarat regarding the effect of the cropping pattern on the adoption of microirrigation technologies. In Maharashtra, the share of fruit crops in the cropping system had a significant effect on adoption probability, while in Gujarat the share of vegetables, cotton and oil seeds (mainly groundnut) had a positive influence on adoption probability. The model also shows that in both states the higher the share of cereals and pulses in the cropping pattern the lower the probability of adoption of microirrigation technologies. However, this relationship was not statistically significant in Maharashtra. These findings are quite in line with the observation of actual conditions in the study areas. In Maharashtra, farmers mainly use microirrigation 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-cum-farming system on the microirrigation adoption process should be evaluated on short- and long-term perspectives. In the short run, as this study indicates, microirrigation systems may bypass certain groups of farmers due to their inherent crop specificity. The bulk of the available microirrigation technologies is 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 microirrigation technology. In the long run, however, this scenario may be reversed due to two possible developments: (1) microirrigation engineers may innovate systems to irrigate crops for which the currently used microirrigation applications are not suitable (Polak et al. 1997), and (2) farmers may shift their cropping patterns to benefit from innovations in microirrigation technology. The latter response will have substantial impacts on the water resources economy of a watershed or basin and also on cash crop prices.

All the socioeconomic variables, namely, membership in a high caste group, poverty index and share of income from off-farm and non-farm activities, in order of quantitative significance (see the respective marginal effect values in table 7), had significant impacts on the decision to adopt microirrigation technology. On average, well-to-do farmers are most likely to adopt microirrigation technologies in both states. An in-depth analysis of the poverty outreach of different microirrigation technologies is presented in the section on *Degree of Poverty Outreach of Alternative Microirrigation Technologies* (page 25).

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 increases, the likelihood of adopting microirrigation 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 microirrigation technologies because agriculture loses its importance and is no longer the primary source of livelihood. The situation in Gujarat is the exact opposite of that in Maharashtra. In the Gujarat case, as the share of income from off-farm and non-farm sources increases the likelihood of adopting microirrigation technologies decreases up to a certain point and then increases. This may be the reflection of the differences in the nature of off-farm and non-farm activities between the two study locations.

Agro-economic Analyses of Microirrigation Technologies

This section presents the results of agro-economic analyses (i.e., yield responses, and technical and economic efficiency of agronomic and irrigation technology inputs) and poverty impact analyses (i.e., the poverty outreach of microirrigation technologies) and discusses the resultant implications for extension, poverty reduction and sustainable water (groundwater) management. The estimated results of the transcendental production function fitted to data to assess the yield responses of the different agronomic and water management inputs are presented in table 8. The results of the technical and economic efficiency analyses are presented in tables 9 through 11 and figures 5 to 8 depict the extent of poverty outreach of microirrigation technologies.

Yield Responses

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

The coefficient for a variable in the natural log form, α_i, measures the elasticity of the output to the use of the input, while the coefficient for a variable in levels (γ_i) measures the rate of change in the elasticity of production.

Among the agronomic inputs, the highest banana yield response was observed for pesticide application followed by that for potassium. The coefficient for the banana yield response to phosphorus suggests 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. The coefficient for the level of irrigation water use (as indicated by pumping hours per hectare) in groundnut production is positive both in the actual level and log form. This indicates that the farmers are currently applying an insufficient level of irrigation water to groundnut. 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 that for nitrogen.

The transcendental yield response function indicates that for all of the three crops considered (banana, groundnut and cotton), the use of microirrigation technologies generally resulted in a significant yield improvement over the traditional irrigation practices (see the estimates of the d_l coefficient in table 8). 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 the response to drip irrigation. Dhawan (2002) also reported similar observations. In addition, farmers in the study area (in Gujarat) claim that the use of drip technology for groundnut is marred by many technical problems.

The synergistic effect of the various agronomic inputs can be observed from the positive interaction effect coefficient (γ_{ij}). Pesticide-by-seed interaction effect is significant for banana and cotton. This shows that diseases and pests are important production constraints for these crops and that the joint yield effect of these inputs is more than the sum of their independent effects. 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.

TABLE 8.

Results of the transcendental regression model.

No.	*Variable*	Banana		Groundnut		Cotton	
		Coefficient	t-ratio	Coefficient	t-ratio	Coefficient	t-ratio
1	Constant	3.172	1.408	-1.097	-0.630	-5.158	-3.635[c]
2	*Estimates of* γ_i *(agronomic and water management input 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[c]
	Pesticide	-0.378	-2.121[b]	-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[a]	NA	NA	-0.002535	-0.474
	Potassium	-0.003698	-1.251	NA	NA	NA	NA
3	*Estimates of* α_i *(agronomic and water management input in natural log form)*						
	Weeding	0.485	2.324[b]	0.175	1.319	0.0782	0.348
	Seed	-0.08461	-0.38	0.237	1.177	0.612	3.501[c]
	Pesticide	0.647	1.343	0.08841	0.713	0.321	2.743[c]
	Pumping	NA	NA	0.05303	0.410	0.225	2.432[b]
	Nitrogen	0.196	0.63	0.03285	0.218	0.593	2.670[c]
	Phosphorous	-0.524	-1.589	NA	NA	0.04591	0.194
	Potassium	0.575	1.854[a]	NA	NA	NA	NA
4	*Estimates of* d_1 *(microirrigation technology)*						
	Conventional drip	1.214	3.138[c]	NA	NA	1.162	3.516[c]
	Low-cost drip	1.05	2.997[c]	NA	NA	0.911	3.214[c]
	Microtube drip	NA	NA	0.511	1.787[a]	0.627	3.779[c]
	Microsprinkler	NA	NA	0.650	2.876[c]	NA	NA
	Conventional sprinkler	NA	NA	0.591	2.012[b]	NA	NA
5	*Interaction* γ_{ij} *(among selected agronomic and irrigation water input variables)*						
	Pest by seed	0.0000124	1.954[a]	NA	NA	0.0000116	1.690[a]
	Seed by weed	0.0000003	0.478	0.00000001082	1.308	0.0000071	2.444[b]
	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[c]		2.545[c]		4.848[c]	
	Durbin-Watson Statistic	1.753		1.832		1.882	
	N	76		180		115	

[a] Significant at 10% [b] Significant at 5% [c] Significant at 1%

Note: NA = Not available or not applicable.

Technical and Economic Efficiency

The technical and economic efficiency parameters, i.e., Marginal Physical Product (MPP) and Value of Marginal Product (VMP), for different microirrigation technologies, derived from the fitted transcendental response functions discussed in the preceding section, are presented in table 9.[7] The MPP values indicate an extra yield advantage that a farmer obtains when shifting from the traditional irrigation methods to a microirrigation practice. MPP values shown in table 9 indicate that the use of microirrigation 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 microirrigation 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 microirrigation technologies are primarily adopted to save crops, including perennial crops such as orchards and coconut, during drought years by extending the use of the limited water as much as possible.

The yield advantage of the use of drip systems in groundnut cultivation is lower than that of the sprinkler systems. This result confirms the claim by farmers that drip is normally not preferred for groundnut irrigation. The choice between drip and sprinkler irrigation systems is also influenced, in addition to expected yield, by 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 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 percent and a 50 percent subsidy, respectively.

TABLE 9.
Technical and economic efficiency of microirrigation systems.

Crop	Microirrigation technology	MPP (q)	VMP (Rs)	Investment cost (Rs)	Subsidized investment cost (Rs)
Banana	Low-cost drip	142.2	42,659	27,360	13,680
	Conventional drip	181.2	54,353	55,000	27,500
Groundnut	Microsprinklers	6.96	10,301	22,239	11,120
	Microtube 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
	Microtube drip	4.99	8,201	17,087	8,544
	Conventional drip	9.26	15,199	45,825	22,913

Notes: Rs = Indian rupee; US$1.00 = Rs 43.70.
q = quintal; 1 quintal = 100 kilograms.
The price of banana was estimated at Rs 300 per quintal.
MPP = Marginal Physical Product; VMP = Value of Marginal Product.

[7]See Appendix 2 for details of how these MPP values were derived from the fitted transcendental response functions.

The main motive of farmers in using microirrigation technologies, particularly for groundnut, is to plant crops earlier, about a month earlier than the normal practice. They do this for one or more of the following reasons:

- To take advantage of the available water so that they can spread water over a larger extent and establish the crop by the time the monsoon sets in.
- To be able to harvest a normal crop even in case of early withdrawal of the monsoon.
- To create a better soil moisture condition throughout the crop season to obtain higher yields and better output quality as a result of better pod filling.
- To enable early harvesting, thus reducing labor costs.

However, in case the rain continues during September (harvest time), the quality of the produce may be adversely affected. The other rationale for adopting microirrigation in groundnut is to save water for use in the cultivation of pearl millet and vegetables in summer.

Technical efficiency alone does not guarantee economic efficiency. A farmer may well operate in the technically 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 microirrigation technologies we need to consider the input-output price relationships. In the present case, this was achieved through calculating the VMP for each of the microirrigation technologies and comparing it with their respective initial investment costs under two scenarios, i.e., actual costs and subsidized costs (see table 9).

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,[8] except for microtube drip and conventional sprinklers under groundnut, all of the microirrigation technologies are economically efficient and the farmers can recuperate their initial investment capital within 1 to 3 years.
- Subsidies further increased the profitability of investments in microirrigation technologies.
- The magnitude of economic gains from investments in microirrigation technologies depends on the type of crop. Microirrigation technology use in banana is highly remunerative, and cotton comes second in this respect. 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.
- An investment in conventional drip systems is economically more rewarding than that in low-cost drip systems.

One of the advantages of microirrigation technologies recognized by the sample farmers in this study, and often also claimed by those in 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 to microirrigation technologies and traditional irrigation methods for groundnut and cotton and calculated the MPP and VMP values (see tables 10 and 11). The results for groundnut are entirely consistent with our expectations in that the calculated MPP and

[8] Ideally the VMP figures ought to be compared to the annual ownership cost of microirrigation technologies, which obviously is a fraction of the initial investment cost.

TABLE 10.
Technical and economic efficiency of other agronomic inputs for groundnut under different irrigation methods.

Agronomic input	Unit input price (Rs)	Traditional methods		Sprinkler systems	
		MPP (q)	VMP (Rs)	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 cost (Rs)	1	0.001738573	2.6	0.00233	3.4
Seed cost (Rs)	1	0.000638345	0.9	0.00107	1.6
Pumping (hours)	32.5	0.014114507	20.9	0.03340	49.4

Notes: Rs = Indian rupee; US$1.00 = Rs 43.70.
q = quintal; 1 quintal = 100 kilograms.
The price of groundnut was estimated at Rs 1,480 per quintal.
MPP = Marginal Physical Product; VMP = Value of Marginal Product.

TABLE 11.
Technical and economic efficiency of other agronomic inputs for cotton under different irrigation methods.

Agronomic input	Unit input price (Rs)	Traditional methods		Drip systems	
		MPP (q)	VMP (Rs)	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 (hours)	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

Notes: Rs = Indian rupee; US$1.00 = Rs 43.70
q = quintal; 1 quintal = 100 kilograms.
The price of cotton was estimated at Rs 1,642 per quintal.
MPP = Marginal Physical Product; VMP = Value of Marginal Product.

VMP values under sprinkler irrigation systems are higher than that for traditional irrigation methods. Thus, microsprinklers do enhance the marginal productivity of other agronomic inputs. However, the farmers are applying more water and nitrogen to groundnut under the traditional method of irrigation than economically justifiable.

The results for cotton are mixed in that contrary to the expectations the MPP figures for seed, phosphorus and pesticide are higher for traditional irrigation methods than that under drip irrigation systems. However, there are justifiable reasons for these anomalies. For instance, farmers claim that with the drip method of irrigation cotton plants are not able to make full use of DAP applied as basal fertilizer and that in most cases the fertigation tank attached to the 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 the Bt cotton[9] variety among fields irrigated through traditional methods (flooding). The Bt cotton variety is resistant to the bollworm (enabling savings in pesticide costs) and is high 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 is shown that the use of microirrigation 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). The investment costs can be recovered within just one or two years of use, particularly given the generous subsidy schemes. This motivates farmers to invest more in groundwater development. This argument is substantiated by the fact that farmers in the two study locations often sink wells close to each other creating fierce competition with subsequent stress on the aquifer resources. However, economics, though important, is not sufficient to explain the farmers' adoption behavior.

Degree of Poverty Outreach of Alternative Microirrigation 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 microirrigation adopters and non-adopters can be compared to indicate the extent to which microirrigation technologies reach the poor. To do this, an appropriate definition of the poor has to be adopted. Since the target of NGOs engaged in the development and dissemination of microirrigation technologies (such as IDE and APPROTEC) is the poorest section of the farming population in India, 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. This is because the non-adopters represent the unbiased sample of the general population. Then the cutoff values for the quintiles of non-adopters were used to group the sample of microirrigation adopters.

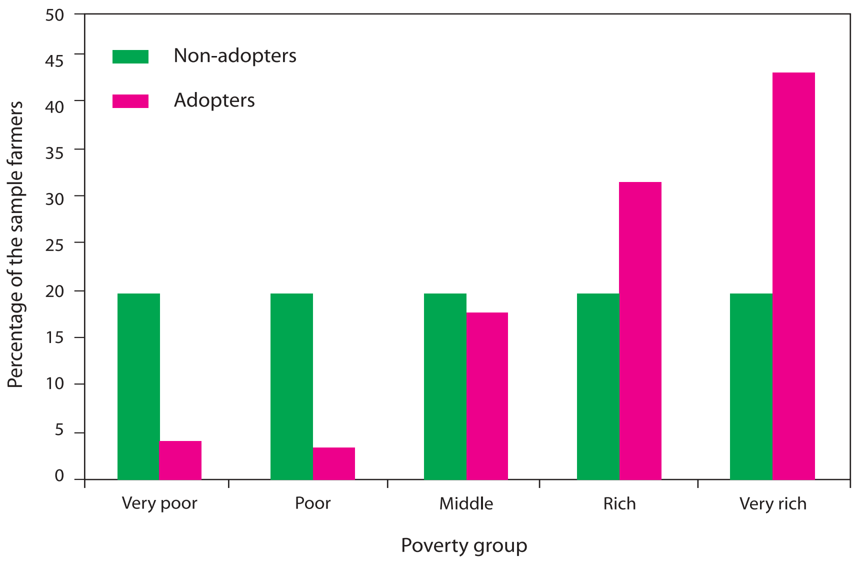
The poverty outreach of microirrigation technologies was assessed by drawing bar graphs of the distributions of the microirrigation adopting and non-adopting samples by poverty quintiles and then visually inspecting the pattern of distribution (see figures 5 and 6). By default, the bars for non-adopters are expected to be equal in size across the poverty groups and, if microirrigation technologies are poverty-neutral, the distribution for adopters is expected to follow a similar pattern to that of non-adopters. However, this is not true in the present case.

In Gujarat, the current microirrigation adopters are somewhat evenly distributed among the middle, rich and very rich groups (figure 5). As figure 6 shows, currently the largest proportion of microirrigation technology adopters in Maharashtra belongs to the relatively very rich group. The slight difference in the pattern of poverty-microirrigation adoption interaction between Gujarat and Maharashtra may be because many NGOs are operating in Gujarat. However, in both Maharashtra and Gujarat, the poor and the very poor categories are the least represented.

Thus, the direct poverty impact of the technologies is not substantial at the moment. However, the different microirrigation technologies have different levels of direct poverty impacts (see figures 7 and 8). This can be visualized by determining how much the bar graphs for the different kinds of microirrigation technologies deviate from that of the traditional irrigation methods. The most commonly reported view is that low-cost

[9]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 that kill bollworms.

FIGURE 5.
Poverty outreach of microirrigation technologies in Gujarat.



microirrigation technologies (low-cost drip such as pepsee, easy drip, and microsprinklers) are easily accessible to poor farmers by virtue of their low capital requirements. However, this study shows that the very rich farmers represent the highest proportion of low-cost drip technology adopters in both Maharashtra and Gujarat. In the case of Gujarat, none of the very poor farmers have yet accessed low-cost drip technologies.

FIGURE 6.
Poverty outreach of microirrigation technologies in Maharashtra.

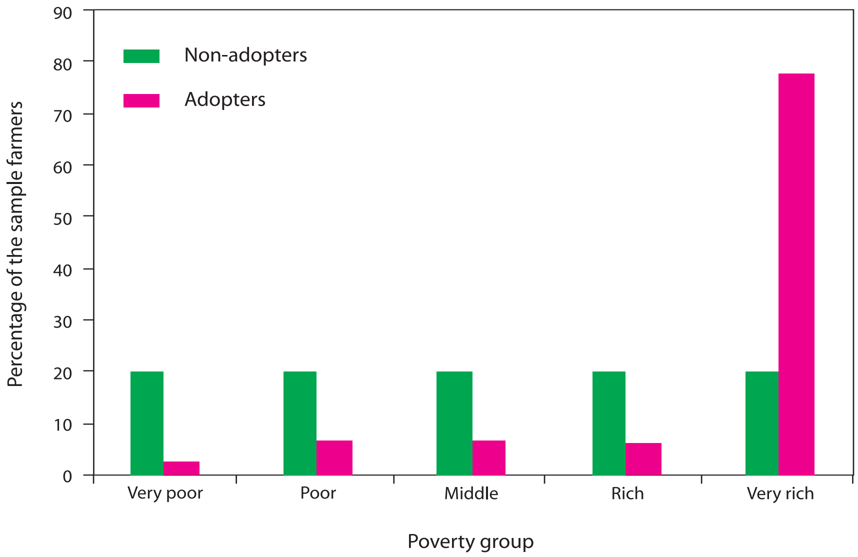


FIGURE 7.
Poverty outreach of different microirrigation technologies in Maharashtra.

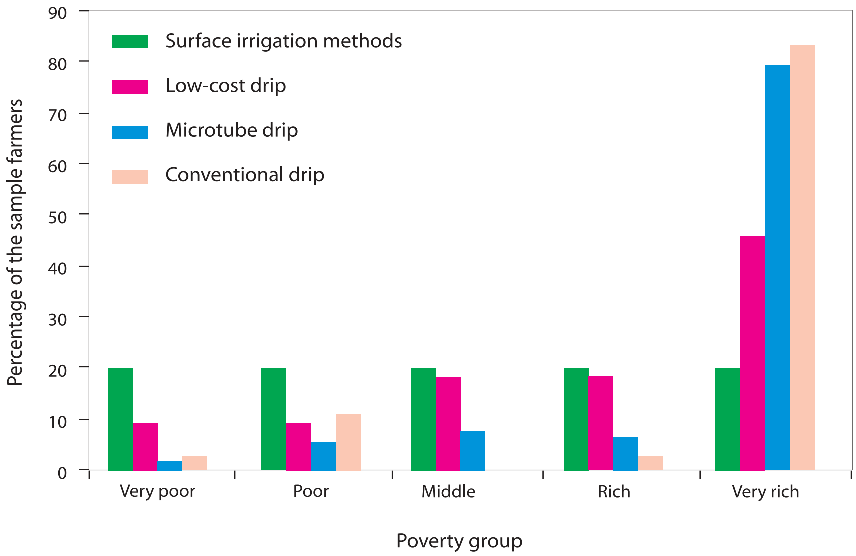
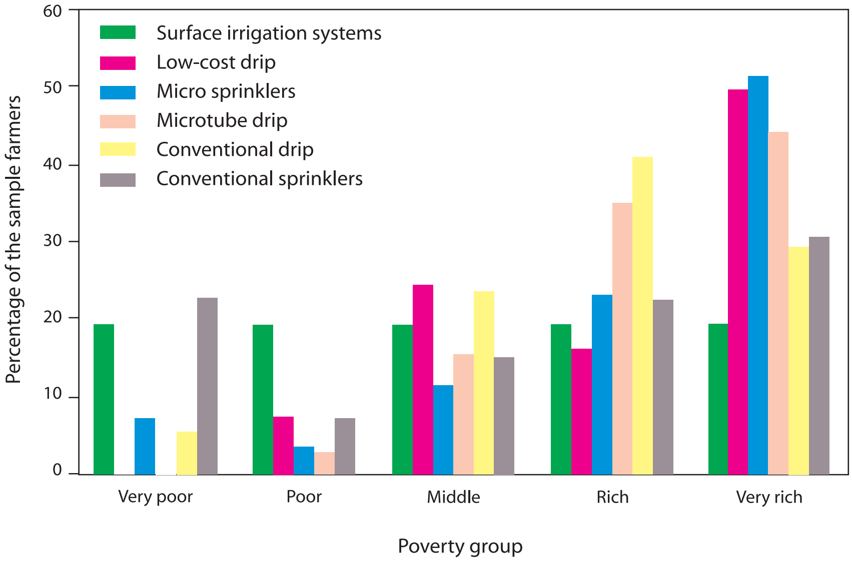


FIGURE 8.
Poverty outreach of different microirrigation technologies in Gujarat.



Other Impacts of Microirrigation Adoption

Changes in Cropping Pattern

The shifts from the traditional flooding/furrow method of irrigation to the use of microirrigation have multifaceted impacts both at the household level and at the higher scale of spatial and socioeconomic aggregation. One remarkable effect in the study locations has been the significant change in the cropping pattern that occurred following the adoption of microirrigation technologies (table 12). It can be seen that the two locations greatly differ in cropping pattern irrespective of the microirrigation adoption status owing to differences in the agro-ecological settings.

A close scrutiny of the data displayed in table 12 reveals the following main points regarding the cropping pattern difference between adopters and non-adopters in Gujarat.

- The proportion of microirrigation adopters growing cotton and vegetables is significantly higher than that of non-adopters.
- Lower proportions of microirrigation adopters cultivate cereals than non-adopters. In addition, the types of cereal grown by the two groups of farmers significantly differ. Adopters grow mainly wheat, while the non-adopters grow the traditionally drought-tolerant cereals such as pearl millet and sorghum.
- A slightly higher proportion of farmers in the non-adopter category grows fruit crops than the adopters. However, the types of fruit crop cultivated by the two groups are different. Microirrigation adopters produce high-value but water-intensive fruit crops such as banana, while the major fruit crop grown by non-adopters is coconut.
- Microirrigation adopters cultivate more diverse crops during the year than the non-adopters.

Almost similar situations were observed in Maharashtra. The following points may be made regarding the 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 microirrigation adopters in Maharashtra that grow high-value fruit crops, such as banana, is significantly higher than that of non-adopters. The average banana area cultivated is also significantly higher for microirrigation adopters.
- Similar to the case of Gujarat, microirrigation adopters in Maharashtra cultivate more diverse crops within a year than non-adopters.

TABLE 12.
Comparison of the cropping patterns of microirrigation 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

The adoption of microirrigation technologies helped some farmers to grow Rabi and summer crops. Figure 9 depicts the trend of the area under microirrigation by farmers in the sample differentiated by season and location. It can be observed that the microirrigation area has sharply increased during the 5 years from 1999 to 2003 in both Maharashtra and Gujarat, particularly during the Kharif season. Similarly, an increasing trend in the microirrigation area can be observed in figure 9 during the Rabi and summer seasons for Maharashtra farmers. In Gujarat, the change in the microirrigation area during Rabi and summer seasons is not so pronounced.

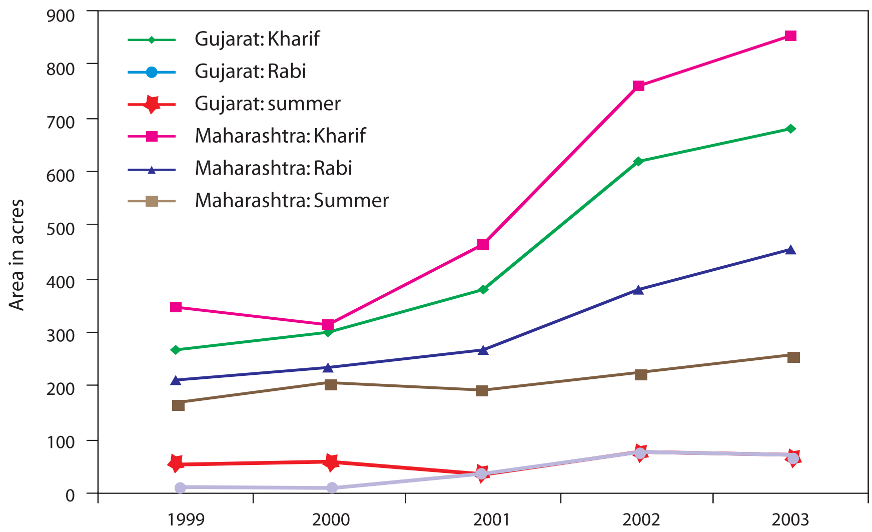
In summary, microirrigation adoption in the two study locations (1) led to the prominence of high-value or water-intensive crops in the farming system, and (2) further improved the cropping intensity. There is a tendency towards the greening of farmlands year round resulting in more evapotranspiration. This obviously will have implications for the sustainable use of groundwater resources.

Impacts on Women

The impact of microirrigation adoption on rural women varies, depending on which of the following socioeconomic categories they belong to: (1) women of landless households, (2) women of small cultivator households, and (3) women of large cultivator households. Moreover, it also depends on the kind of the system adopted. Hence, any generalization of the impact of adoption on women across the board would be inaccurate. Our study suggests a mixed reaction from various adopters.

Our data suggest that women of both study regions adopted drip kits (like drum and bucket) either to generate additional income or to improve nutritional intake. These adopters belonged to small cultivator households. Women were found to be involved in the operation and use of the kits for vegetable farming in homesteads. Therefore, the adoption does not necessarily reduce their workloads; the workloads increase because they have to carry out all the farming activities,

FIGURE 9.
Area under microirrigation during 1999-2003.



Note: 1.00 acre = 0.40468 hectare.

sometimes including even marketing. However, the additional employment opportunity offered by the technology at the homesteads saves travel time and the privation that often accompanies working away from home. This is significant for women as they can work without fear of harassment or humiliation and can take care of young children at the same time. Moreover, household nutritional intake has significantly improved as the families have started eating green vegetables regularly. Our qualitative discussion revealed that women's relative access to income had also improved as they received the revenue from the sale of vegetables.

In the study locations, women provide a substantial share of the labor input for intercropping, harvesting and irrigating during daytime. Besides, women perform all the household chores and agricultural activities, except physically demanding work like the use of heavy equipment. Men are more involved in procurement, marketing and the financial management of agricultural activities.

Our qualitative data suggest that women of landless households were not able to benefit much, in both study regions. These women usually work as wage earners. The reduction in the availability of weeding jobs due to the introduction of microirrigation, particularly customized systems, reinforced the vulnerability of women of the landless category as these women found a significant decline in their labor requirement due to lesser growth of weeds. Microirrigation technology, on the one hand, reduces the number of hours or days required for weeding while, on the other, it diminishes the earning opportunities. The situation deteriorates further when these women have to take the overall burden of raising children and sustaining the household due to the out-migration of male members, an increasingly common phenomenon in rural areas.

Women of households owning a customized system, who are large cultivators in the surveyed locations, benefited from the technology as it led to a reduction in the labor requirement. The decline in labor inputs also helped save cash that such families used to pay to female labor for weeding. Bilgi (1999) reported similar findings from Aurangabad and Bijapur. Those households that used hired labor for irrigation and other agronomic activities realized significant money savings. A lesser labor requirement implies the availability of more leisure time to share with the family or to utilize in other productive activities.

In summation, the category of women that benefited most from the adoption of microirrigation technologies was small cultivators, as they could improve their own access to income and their family nutritional intake. The landless category was negatively affected due to the reduction of the labor requirement caused by the technology. And, women of large cultivator households found it beneficial as their workload was reduced.

With regard to the impact of adoption on women's household decision making, data suggest that there was no significant change where women of landless and large cultivator households were concerned. However, the decision-making power of small cultivator women was found to be affected by adoption. Before adoption, women were hardly consulted by their male counterparts while the majority of decisions were made jointly after adoption. Hence, the introduction of the technology has helped achieve greater participation and empowerment of these women.

Food and Nutritional Security Impacts

With regard to the effects of microirrigation on food and nutritional intake, our data reveal that mainly the small cultivator category of farmers had benefited in terms of access to fresh vegetables and improvement in nutritional intake. This was because of the direct involvement of women small cultivators in vegetable cultivation on the homestead farm, which earlier used to remain barren. The adoption of drip and bucket helped these women grow vegetables, which was used primarily for household consumption, while the surplus was sold.

As women small cultivators were involved directly in market transactions, they had access to and control over the revenue generated from the sale of vegetables. This access and control over income had a positive impact on overall household food security, as a majority (82 percent) of these women spent most of the revenue on household food items. For landless families, the intervention of drip and bucket did not have any effect on their normal food intake habits. Likewise, large cultivator households preferred to buy their vegetables as they used to do earlier, hence no change has been found in their eating habits.

This implies that the effect of the adoption on improvement in household food security and nutritional intake is more pronounced for those farmers who adopt bucket and drip for homestead vegetable cultivation. This finding corroborates the observation of Upadhyay and Samad (2004) who in their study of microirrigation in the western hills of Nepal noted that women farmers were able to ensure improvements in their vegetable and fruit intakes after adopting drum kits.

Conclusions and Implications

Economics of microirrigation systems

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

Determinants of microirrigation adoption

Technical and economic efficiency is only one of the many variables that influence microirrigation adoption decisions of farmers. If technical and economic efficiency alone is the main determinant of adoption, microirrigation technologies would have dominated the traditional irrigation methods. The successful adoption of microirrigation requires, in addition to technical and economic efficiency, two additional preconditions:

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 services in the form of demonstrations, workshops, etc. 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.
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 institutional support systems.

The most important variables influencing microirrigation adoption decisions in the present context are:

1. *Years of schooling of the household head*. As the level of education of the household head increases the likelihood of adopting microirrigation technologies increases. This confirms the fact that microirrigation 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 programs need to be instituted to enable poor people adopt and successfully manage microirrigation systems.

2. *Access to groundwater*. As expected, ownership of dug wells and/or bore wells significantly increases the probability of adoption of microirrigation technologies. Moreover, as the depth of dug wells and the horsepower of pumps owned by farmers increase the likelihood of adopting microirrigation technologies increases. The depth of well and horsepower of pump indicate the degree of water scarcity and the energy-saving motives of the farmer.

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 microirrigation technologies. This implies that farmers cultivating staple food crops are largely excluded from the benefits of innovations in microirrigation technologies. In the long run, this scenario may be reversed through two possible developments. First, microirrigation engineers may innovate systems better suited for staple food crops, which currently do not benefit much from microirrigation applications. Second, the farmers may shift their cropping pattern in order to benefit from microirrigation technologies. The latter response will have significant implications on the water resources economy of a watershed or a region.

4. *Additional sources of income*. As the share of income from other sources than farming (excluding wage-labor income) increases, the probability of adopting low-cost microirrigation 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 microirrigation technologies to make them pro-poor, well-to-do farmers still have a significantly higher probability of adopting microirrigation technologies. In addition, farmers belonging to the high-caste category have more chance of adopting microirrigation technologies.

Microirrigation technologies, poverty and women

The largest proportion of microirrigation adopters belongs to the relatively very rich 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 sections of the farming population have not benefited much from innovations in microirrigation technology. One view widely held among development NGOs in India and elsewhere is that the technical transformation of the conventional, capital-intensive systems into low-cost alternatives greatly improves the accessibility of these technologies to the poor. Even though this claim is theoretically or potentially true, the observed adoption pattern in the study locations does not lend full support to this view. Though there is slight improvement, at the moment the majority of the adopters of low-cost microirrigation technologies are those farmers belonging to the middle, rich and the richest groups.

Thus, reducing the cost alone is not enough to improve the poverty outreach of microirrigation technologies. Three factors limited poor farmer’s access to low-cost microirrigation technologies. First, the available low-cost microirrigation 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. Second, their socioeconomic attributes (e.g., low level of education, being a member of a low-caste group, low poverty status, etc.) limit their access to information, ultimately hindering their access to microirrigation technologies. Last, limited access to resources, specifically to groundwater, quantitatively and qualitatively, hinders poor farmers from successfully adopting low-cost microirrigation technologies.

Analysis of impacts of microirrigation on women in both study regions revealed that women of small cultivator households benefited most in terms of access to and control over income and household nutritional security. Landless, wage earner women experienced negative impacts of microirrigation technology as their earning opportunities as wage earners had significantly declined because of reduction in weeding requirements. Women of large cultivator households benefited since their workload as family labor, particularly in weeding, declined.

Microirrigation use and sustainable utilization of groundwater resources

The sustainability impact of microirrigation use depends on:

1. the magnitude of the overall productivity gain following the shift from traditional methods of irrigation to microirrigation systems (or, indirectly, the volume of water that is saved for other irrigation uses due to improvements in the productivity of water),
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 microirrigation 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 until the Value of Marginal Product of water equals the price of water.

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 a normal harvest or to minimize yield losses. Second, those irrigating only part of their potentially irrigable fields due to the inadequacy of water will make use of the saved water to increase the 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 scenarios 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 microirrigation, the groundwater level has substantially declined and the concentrations of wells have increased.

The other remarkable impacts, with significant implications for the sustainable use of groundwater resources, observed in the study locations following the adoption of microirrigation technologies are changes in cropping pattern, cropping intensity and/or crop diversity. Microirrigation adoption led to the prominence of high-value, water-intensive crops in the farming system, and further improved the cropping intensity by enabling the production of crops in the summer or Rabi. Thus, in the long run, the sustainability objective may conflict with the poverty reduction and food security objectives unless a proper regulatory mechanism is instituted.

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Appendix 1

Salient Features of the Study Locations

TABLE A1.
Names of villages and talukas in the study districts.

Administrative unit	Name of the study district, taluka or village								
State	Maharashtra					Gujarat			
District	Jalgaon					Rajkot			Junagadh
Taluka	Chopda	Jalgaon	Jamner	Pachora	Raver	Jetpur	Kotada Sangani	Rajkot	Maliya
Village	Devagon	Edgaon	Gondegaon	Kalamsare	Vivare	Umrali	Ramond	Khokhadadad	Babra
	Dhanora	Dexie	Shengole	Lohatar	Kerhale			Lothada	Kukaswada
	Pargaon		Vidgaon	Lohare					Laduli
				Lohari					Moti Dhanej
									Nani Dhanej
									Shanti Pura

TABLE A2.

Basic information on demographics, land use and irrigation infrastructure in the study locations.

Characteristic	Rajkot		Junagadh		Gujarat		Jalgaon		Maharashtra	
	1992	2001	1992	2001	1992	2001	1992	2001	1992	2001
Rural population	1,330,156	1,562,383	1,615,483	1,737,101	27,063,521	31,740,767	2,312,965	2,627,315	48,395,601	55,777,647
Urban population	1,183,966	1,595,293	779,376	711,326	14,246,061	18,930,250	874,669	1,052,621	30,541,586	41,100,980
Total population	2,514,122	3,157,676	2,394,859	2,448,427	41,309,582	50,671,017	3,187,634	3,679,936	78,937,187	9,6878,627
Total geographic area (ha)	1,120,300	1,120,300	1,060,700	1,060,700	196,11,700	19,611,700	1,163,900	1,163,900	30,758,300	30,758,300
Net area sown (ha)	723,700	737,400	573,000	587,200	9,347,100	9,667,400	830,200	852,500	17,894,800	17,636,400
Area sown more than once (ha)	49,800	70,700	60,200	84,000	1,210,600	1,476,400	140,100	480,600	2,238,600	4,619,400
Gross cropped area (ha)	773,500	808,100	633,200	671,200	10,557,700	11,143,800	970,300	1,333,100	20,133,400	22,255,800
Net irrigated area: Surface irrigation (ha)	13,400	40,900	7,500	12,200	507,500	651,900	7,400	11,000	980,400	1,050,200
Net irrigated area: Well irrigation (ha)	151,600	107,600	102,500	140,200	1,930,100	2,430,500	131,600	144,400	1,745,500	2,090,000
Total net irrigated area (ha)	165,000	148,500	110,000	152,400	2,437,600	3,082,400	139,000	155,400	2,725,900	3,140,200
Area irrigated more than once (ha)	5,600	63,000	12,300	9,400	472,900	758,200	29,600	16,700	538,900	553,000
Gross area of irrigated crops (ha)	170,600	211,500	122,300	161,800	2,910,500	3,840,600	168,600	172,100	3,264,800	3,693,200
Groundwater structures (1994)[a]	-		-		722,958		-		1,350,274	
Government tube wells (1998)	-		-		-		169		35,149	
Private tube wells (1998)	-		-		-		1,705		36,143	
Other government wells (1998)	-		-		-		0		39,746	
Other private wells (1998)	-		-		-		62,121		1,237,067	
Oil engine pump sets (1998)							775		122,422	
Electric pump sets (1998)							48,531		1,080,954	
Districts with recorded decline in water level (1999-2002)	Yes[b]		Yes[b]		5		Yes[b]		27	
Range of pre-monsoon groundwater decline in meters (1999-2002)	-				0.45-3.32				0.15-2.68	
Number of wells drilled as of November 2000	-		-		579				693	

[a] Includes groundwater developed for other purposes than irrigation.

[b] Indicates whether the study location was included in the list of districts with recorded decline in water level (1999-2002).

TABLE A3.
Cropping patterns of the study locations for the year 1991/1992.

	Rajkot		Junagadh		Gujarat		Jalgaon		Maharashtra	
Category	ha	%	ha	%	ha	%	ha	%	ha	%
Cereals	105,000	13.6	91,000	14.4	3,731,900	35.4	366,500	37.8	9,990,600	49.6
Pulses	11,600	1.5	9,700	1.5	882,700	8.4	174,900	18.0	3,080,800	15.3
Sugarcane	4,500	0.6	9,500	1.5	172,600	1.6	20,400	2.1	588,600	2.9
Condiments and spices	11,500	1.5	4,900	0.8	139,200	1.3	4,400	0.5	150,700	0.7
Banana	0	0.0	400	0.06	32,300	0.3	44,800	4.6	72,400	0.4
Other fruit crops	800	0.1	6,000	1.0	67,500	0.6	2,400	0.3	171,500	0.9
Vegetables	7,000	0.9	3,400	0.5	105,700	1.0	3,500	0.4	238,500	1.2
Groundnut	434,300	56.1	418,300	66.1	1,976,100	18.7	53,600	5.5	739,000	3.7
Other oil seeds	36,700	4.7	15,000	2.4	888,400	8.4	93,500	9.6	1,534,600	7.6
Cotton	90,300	11.7	31,400	4.9	1,164,300	11.0	204,000	21.0	2,759,100	13.7
Other fiber crops	0	0.0	0	0.0	8,800	0.08	200	0.02	38,700	0.2
Narcotics and plantation crops	700	0.1	100	0.01	179,000	1.7	0	0.0	8,700	0.04
Fodder crops	71,100	9.2	43,300	6.8	1,205,500	11.4	2,000	0.2	751,500	3.7
Others	0	0.0	200	0.03	3,700	0.04	100	0.01	7,700	0.04
Total	773,500	100	633,200	100	10,557,700	100	970,300	100	20,132,400	100

Appendix 2

Derivation of the MPP from the Fitted Transcendental Production Function

Banana

$$Y_b = AW^{\alpha_1} S^{\alpha_2} PE^{\alpha_3} N^{\alpha_4} K^{\alpha_5} P^{\alpha_6} e^{(\gamma_1 W + \gamma_2 S + \gamma_3 PE + \gamma_4 N + \gamma_5 K + \gamma_6 P + \gamma_7 CNMI + \gamma_8 LCMI + \gamma_9 NxK + \gamma_{10} PExS + \gamma_{11} SxW)}$$

$$MPP_W = \partial y_b / \partial w = (\alpha_1 / W + \gamma_1 + \gamma_{11} S) Y_b$$

$$MPP_S = \partial y_b / \partial S = (\alpha_2 / S + \gamma_2 + \gamma_{10} PE + \gamma_{11} W) Y_b$$

$$MPP_{PE} = \partial y_b / \partial PE = (\alpha_3 / PE + \gamma_3 + \gamma_{10} S) Y_b$$

$$MPP_N = \partial y_b / \partial N = (\alpha_4 / N + \gamma_4 + \gamma_9 K) Y_b$$

$$MPP_K = \partial y_b / \partial K = (\alpha_5 / K + \gamma_5 + \gamma_9 N) Y_b$$

$$MPP_P = \partial y_b / \partial P = (\alpha_6 / P + \gamma_6) Y_b$$

$$MPP_{CNMI} = \partial y_b / \partial CNMI = \gamma_7 Y_b$$

$$MPP_{LCMI} = \partial y_b / \partial LCMI = \gamma_8 Y_b$$

Where:

Y_b = Banana yield per ha; A= Constant term; W = Weeding labor input (man-days per ha); S = Seed cost (Rs per ha); PE = Pesticide (l per ha); N = Nitrogen (kg per ha); K = Potassium (kg per ha); P = Phosphorus (kg per ha); MPP_w = Marginal Physical Product of weeding labor input; MPP_s = Marginal Physical Product of seed input; MPP_{PE} = Marginal Physical Product of pesticide input; MPP_N = Marginal Physical Product of nitrogen; MPP_K = Marginal Physical Product of potassium; MPP_P = Marginal Physical Product of phosphorus; MPP_{CNMI} = Marginal Physical Product of conventional microirrigation system; MPP_{LCMI} = Marginal Physical Product of low-cost microirrigation system.

Groundnut

$$Y_{GN} = AW^{\alpha_1} S^{\alpha_2} PE^{\alpha_3} N^{\alpha_4} K^{\alpha_5} PU^{\alpha_6} e^{(\gamma_1 W + \gamma_2 S + \gamma_3 PE + \gamma_4 N + \gamma_5 PU + \gamma_6 CNSP + \gamma_7 misp + \gamma_8 drip + \gamma_9 wXs)}$$

$$MPP_W = \partial y_{GN} / \partial W = (\alpha_1 / W + \gamma_1 + \gamma_9 S) Y_{GN}$$

$$MPP_S = \partial y_{Gn} / \partial S = (\alpha_2 / S + \gamma_2 + \gamma_9 W) Y_{GN}$$

$$MPP_{PE} = \partial y_{GN} / \partial PE = (\alpha_3 / PE + \gamma_3) Y_{GN}$$

$$MPP_N = \partial y_{GN} / \partial N = (\alpha_4 / N + \gamma_4) Y_{GN}$$

$$MPP_K = \partial y_{GN} / \partial K = (\alpha_5 / K) Y_{GN}$$

$$MPP_{PU} = \partial y_{GN} / \partial PU = (\alpha_6 / PU + \gamma_5)Y_{GN}$$

$$MPP_{CNSP} = \partial y_{GN} / \partial CNSP = \gamma_6 Y_{GN}$$

$$MPP_{MISP} = \partial y_{GN} / \partial MISP = \gamma_7 Y_{GN}$$

$$MPP_{DRIP} = \partial y_{GN} / \partial DRIP = \gamma_8 Y_{GN}$$

Where:

Y_{GN} = Groundnut yield per ha; A = Constant term; W = Weeding labor input (man-days per ha); S = Seed cost (Rs per ha); PE = Pesticide (l per ha); N = Nitrogen (kg per ha); K = Potassium (kg per ha); PU = Pumping hours (hour per ha); MPP_w = Marginal Physical Product of weeding labor input; MPP_s = Marginal Physical Product of seed input; MPP_{PE} = Marginal Physical Product of pesticide input; MPP_N = Marginal Physical Product of nitrogen; MPP_K = Marginal Physical Product of potassium; MPP_{PU} = Marginal Physical Product of pumping hours; MPP_{CNSP} = Marginal Physical Product of conventional sprinkler system; MPP_{MISP} = Marginal Physical Product of microsprinkler system; MPP_{DRIP} = Marginal Physical Product of drip system.

Cotton

$$Y_{CN} = AW^{\alpha_1} S^{\alpha_2} PE^{\alpha_3} N^{\alpha_4} P^{\alpha_5} PU^{\alpha_6} e^{(\gamma_1 W + \gamma_2 S + \gamma_3 PE + \gamma_4 N + \gamma_5 P + \gamma_6 PU + \gamma_7 CNDP + \gamma_8 MITD + \gamma_9 LCMI + \gamma_{10} WS + \gamma_{11} SPE + \gamma_{12} WPE + \gamma_{13} PUS)}$$

$$MPP_W = \partial y_{CN} / \partial W = (\alpha_1 / W + \gamma_1 + \gamma_{10} S + \gamma_{12} PE)Y_{CN}$$

$$MPP_S = \partial y_{CN} / \partial S = (\alpha_2 / S + \gamma_2 + \gamma_{10} W + \gamma_{11} PE + \gamma_{13} PU)Y_{CN}$$

$$MPP_{PE} = \partial y_{CN} / \partial PE = (\alpha_3 / PE + \gamma_3 + \gamma_{11} S + \gamma_{12} W)Y_{CN}$$

$$MPP_N = \partial y_{CN} / \partial N = (\alpha_4 / N + \gamma_4)Y_{CN}$$

$$MPP_P = \partial y_{CN} / \partial P = (\alpha_5 / P + \gamma_5)Y_{CN}$$

$$MPP_{PU} = \partial y_{CN} / \partial PU = (\alpha_6 / PU + \gamma_6 + \gamma_{13} S)Y_{CN}$$

$$MPP_{CNDP} = \partial y_{CN} / \partial CNDP = \gamma_7 Y_{CN}$$

$$MPP_{MITD} = \partial y_{CN} / \partial MITD = \gamma_8 Y_{CN}$$

$$MPP_{LCMI} = \partial y_{CN} / \partial LCMI = \gamma_9 Y_{CN}$$

Where:

Y_{CN} = Cotton yield per ha; A = Constant term; W = Weeding labor input (man-days per ha); S = Seed cost (Rs per ha); PE = Pesticide (l per ha); N = Nitrogen (kg per ha); P = Phosphorus (kg per ha); PU = Pumping hours (hour per ha); MPP_w = Marginal Physical Product of weeding labor input; MPP_s = Marginal Physical Product of seed input; MPP_{PE} = Marginal Physical Product of pesticide input; MPP_N = Marginal Physical Product of nitrogen; MPP_P = Marginal Physical Product of phosphorus; MPP_{PU} = Marginal Physical Product of pumping hours; MPP_{CNDP} = Marginal Physical Product of conventional drip system; MPP_{MITD} = Marginal Physical Product of microtube drip system; MPP_{LCMI} = Marginal Physical Product of low-cost microirrigation system.

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Sri Lanka

Location:
127, Sunil Mawatha
Pelawatta
Battaramulla
Sri Lanka

Tel:
+94-11-2787404

Fax:
+94-11-2786854

E-mail:
iwmi@cgiar.org

Website:
http://www.iwmi.org

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FUTURE HARVEST
IWMI is a Future Harvest Center supported by the CGIAR

ISSN 1026-0862
ISBN 92-9090-602-2