WATER SAVING AND YIELD ENHANCING MICRO-IRRIGATION TECHNOLOGIES IN INDIA : WHEN AND WHERE CAN THEY BECOME BEST BET TECHNOLOGIES?

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Abstract

A systematic attempt to determine the conditions under which, micro irrigation (MI) systems become the "best bet technology" in terms of realizing the potential benefits, and extent of reduction in crop water requirement possible through such systems is crucial for assessing our ability to address future water scarcity at the regional and national level. The ultimate objective of this research is to find out under what conditions micro irrigation system offer the best bet technology, and what benefits it can yield. The research aims at determining the potential benefits from the use of MI systems in India. This is done through assessing: a] the conditions that are favourable for MI system adoption; b] the field level and aggregate level impacts of the systems on water use; and c] the yield and economic benefits from adoption. The research also aims at assessing the potential future coverage of MI systems in India, and the potential reduction in aggregate water requirement in crop production.

The research used extensive review of published and unpublished literature on the feasibility, and physical and economic impacts of various MI systems; results from field experiments carried out by IWMI in one location in Gujarat on the techno-economic viability of some MI devices; data from field-based research carried out by IWMI researchers on the economic viability of MI systems; and statistics on MI adoption in India.

The constraints in MI system adoption are: i] lack of independent source of water and pressurizing device for many farmers; ii] poor quality of groundwater in many semi arid and arid regions; iii] the mismatch between water delivery schedules and irrigation schedules required in MI systems in surface irrigation systems; iv] cropping systems that dominate field crops in semi arid regions; v] dominance of small and marginal farmers, and small plot sizes; vi] low opportunity costs of pumping groundwater due to lack of well-defined water rights; vii] negative technical externalities in groundwater use; viii] poor extension services; and viii] poor administration of subsidies.

The other findings are: 1] the extent of real water-saving and water productivity gains at the field level from adoption of MI systems varies across crops, climate, geo-hydrology and type of MI devices used; 2] the potential benefits of MI systems in terms of real field level water saving are likely to be realized in semi arid and arid areas with deep water table conditions, for widely spaced row crops; 3] the economics of pressurized MI systems depend on the capital cost of the system, size of the plot, type of crop irrigated, extent of water and energy saving and the market value of the produce; 4] being capital intensive, the economic viability of MI systems is sound for high valued cash crops and orchards, especially in areas where groundwater availability is extremely limited; and 5] in many areas, due to flat rate system of pricing and heavy subsidy in electricity, zero opportunity cost of using groundwater, energy and water saving does not result in cost saving and improved economic returns from MI.

The future potential of MI systems to improve basin water productivity is primarily constrained by the physical characteristics of the basins vis-à-vis the opportunities they offer for real water-saving at the field level and basin water productivity improvements, and area under crops that are conducive to MI in those basins. Preliminary analysis shows a very modest potential of MI systems to the tune of 5.6 million ha, with the impact of drip systems in reducing aggregate water requirement for crop production to the tune of 44.46 BCM. Creating appropriate institutions for technology extension, designing water and electricity pricing and supply policies apart from building proper irrigation and power supply infrastructure would play a crucial role in facilitating large-scale adoption of different MI systems. The subsidies for MI promotion should be targeted at regions, people and technologies level, where MI adoption results in real water and energy saving at the aggregate level, and maximize welfare impacts.

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1. INTRODUCTION

Demand management becomes the key to the overall strategy for managing scarce water resources (Molden et al., 2001). Since agriculture is the major competitive user of diverted water in India (GoI, 1999), demand management in agriculture in water-scarce and water-stressed regions would be central to reducing the aggregate demand for water to match the available future supplies (Kumar, 2003a and 2003b). Improving water productivity in agriculture is important in the overall framework for managing agricultural water demand, thereby increasing the ability of agencies and other interested parties to transfer the water thus "saved" to economically more efficient or other high priority domestic and industrial use sectors (Barker et al., 2003; Kijne et al., 2003).

Three dimensions of water productivity include: physical productivity, expressed in kg per unit of water consumed; combined physical and economic productivity expressed in terms of net return per unit of water consumed, and economic productivity expressed in terms of net income returns from a given amount of water consumed against the opportunity cost of using the same amount of water (Kijne et al., 2003). The discussion in the present paper would be largely on the first parameter, i.e., physical productivity. There are two major ways of improving the physical productivity of water used in irrigated agriculture. First: the water consumption or depletion for producing a certain quantum of biomass for the same amount of land is reduced. Second: the yield generated for a particular crop is enhanced without changing the amount of water consumed or depleted per unit of land. Often these two improvements can happen together with an intervention either on the agronomic side or on the water control side (for discussion on other aspects of water productivity, see Kumar et al., 2007).

There are several conceptual level issues in defining the term "water saving" and irrigation efficiency. This is because with changing contexts and interests, the "unit of analysis" changes from field to farm to irrigation systems to river basins. With the concepts of "dry" and "wet" water saving", which capture the phenomena such as "return flows from field" and "depleted water", becoming dominant in irrigation science literature in the last one decade, the old concepts of "water saving" and irrigation efficiencies have become obsolete. The real water saving or "wet water" saving in irrigated production at the field level can come only from reduction in depleted water and not the water applied (Molden et al., 2001). But, there are methodological and logical issues involved in estimating the depletion fraction of the water effectively applied to the crop. Complex considerations, including agronomic, hydrologic, geo-hydrological and geo-chemical, go into determining the "depletion" fraction. Nevertheless, for the limited purpose of analysis, throughout this paper, "water saving" refers to "wet" water saving.

Water productivity is an important driver in projecting future water demands (Amarasinghe et al., 2004; Kijne et al., 2003). Efficient irrigation technologies help establish greater control over water delivery (water control) to the crop roots, reduce non-beneficial evaporation and non-recoverable percolation[1] from the field, and return flows into "sinks" and often increases beneficial ET, though the first component could be very low for field crops. Water productivity improves with reduction in depleted fraction and yield enhancement. Since at the theoretical level, water productivity improvements in irrigated agriculture can result in saving of water used for crop production, any technological interventions, which improve crop yields, are also, in effect, water saving technologies. Hence, water saving technologies in agriculture can be broadly classified into three: water saving crop technologies; water saving and yield enhancing irrigation technologies; and, yield improving crop technologies.

There are several technologies and practices for water-saving in irrigation. They include: 1) broad beds or small border irrigation; 2) improved furrow irrigation (surge, cutback, proper management) 3) laser leveling of fields; 5) plastic mulches and tunnels; 6) improved soil moisture retention sub-surface barriers; 7) alternative wetting and drying for rice; 8) system of rice intensification; 9) direct seeding of rice; 10) aerobic rice; 11) on-farm storage; and, 12) allowing better control and timing of surface irrigation (micro-irrigation, sprinklers and their variants). But, only micro irrigation technologies, which are based on plastics, are dealt with in this report.

India stands 27th in terms of scale of adopting water-saving and yield enhancing micro irrigation devices (Source: www.oznet.ksu.edu/sdi/News/Whatisnew.htm). There are several constraints to adoption of MI

[1] See Allen et al., (1997) for definitions of non-beneficial evaporation, non-recoverable deep percolation.

devices. These are physical, socio-economic, financial, institutional—pricing, subsidies, extension service and policy-related related (Narayanamoorthy, 1997; Sivanappan, 1998; Kumar, 2002a). Nevertheless, a systematic attempt to find out the conditions under which MI systems become a best bet technology, and assess the magnitude of reduction in water requirement possible through them is hardly ever made. Such efforts are crucial for assessing our ability to address problems of water scarcity in the future at the regional and national level.

The ultimate objective of this research is to find out under what conditions micro irrigation system offer the best bet. It aims at determining the potential benefits from the use of MI systems. This includes assessing: a] conditions that are suitable or unsuitable for MI systems; b] field level and aggregate level impacts of the systems on water use; and c] yield and economic benefits due to adoption of MI system. The research also aims at assessing the potential future coverage of MI systems in India, and the reduction in aggregate water requirement in crop production.

The scope of the report is as follows. First, it provides an over-view of the benefits of "MI technologies. It then covers the present spread of MI systems in India. It deals with the potential physical and economic impacts of MI systems in India. This is based on analysis of: i] physical, socio-economic and institutional constraints for its adoption in the country; ii] field level water saving, and impacts on drivers of water demand; iii] and cost-benefit analysis of MI systems for different crops under different socio-economic conditions, and policy environments. A macro level analysis of the potential future impact of drip systems on agricultural water requirements in India is provided. This is done by: a] assessing the actual cropped areas that can be brought under drip systems in the basins which would benefit from them in terms of water productivity improvements; and b] potential future reduction in water requirement of selected crops through drips. The fifth section deals with the impact of existing water and energy related policies in India, and discussions on institutional and policy alternatives for spreading MI system adoption.

2. AVAILABLE WATER-SAVING AND YIELD IMPROVING IRRIGATION TECHNOLOGIES IN INDIAN AGRICULTURE AND THEIR POTENTIALS

Water-saving and yield enhancing irrigation devices which are in use in India and the crops for which they can be used are given in Table 1. While listing these devices, we have considered their technical feasibility for the crop in question and their actual preference by farmers, and are not based on their analysis of the social costs and benefits of using them. Synthesizing the information provided in the last column, it is clear that highest growth in water productivity would be possible with green house, which reduces the consumptive use of water and enhances the yield substantially.

3 CONTRIBUTION OF MICRO-IRRIGATION TECHNOLOGIES IN INDIAN AGRICULTURE

3.1 Present Spread of Micro-irrigation Technologies in Indian Agriculture

There were no systematic attempts in the past to assess the spread of water-saving irrigation technologies in India. Sivanappan and Lamm (1995) reported that the area under drip irrigation is a mere 7000 ha in 1994. The most recent data shows that nearly 1.3 m ha of irrigated land is under drip irrigation (see Narayanamoorthy, 2004b).

They cited high initial cost (including mis-targetted subsidies), clogging of drippers and cracking of pipes, lack of adequate technical inputs, damages done by rodents; high cost of spare components; and insufficient extension education effort as the major problems in the slow rate of adoption of drips. The National Committee on Irrigation and Drainage also added factors such as salinity hazards to the list of problems (GoI, 1994). Shiyani and others (1999) found difficulty in inter-cultivation another reason for non-adoption, while Palanisamy and others (2002) cited joint ownership of wells as additional reason for non-adoption based on their study in Coimbatore (Tamil Nadu). However, some of the problems listed above such as clogging, lack of adequate technical inputs and high cost of spare components, to a limited extent, are being bypassed with the introduction of low cost micro irrigation systems in India, pioneered by International Development Enterprises.

The recent data released by the Task Force on Micro Irrigation in India shows that during the past four years, peninsular India had recorded highest growth in adoption of drip systems. Maharashtra ranks first, followed by Andhra Pradesh and Karnataka. Table 2 presents the data of adoption of drip irrigation systems under various programmes, viz., macro management plan; technology mission on horticulture; cotton development programme and oil palm development programme. The major crops for which drip systems are currently adopted are: cotton, sugarcane; banana, orange, grapes, pomegranate, lemon, citrus, mangoes, flowers, and coconut.

Table 1: Nature of Water Saving for Different Crops under Different Types of Efficient Irrigation Devices

Sl. No	Name of water-saving and yield enhancing micro irrigation technology	Names of crops for which the technology can be used ideally	Nature of Saving in Applied Water
1.	Pressurized drip systems (inline and on-line drippers, drip tape)	All fruit crops; cotton; castor; fennel; maize; coconut; arecanut; chilly; cauliflower; cabbage; ladies finger; tomatoes; egg plant; gourds; mulberry; sugarcane; water melon1 ; flowers	1. Reduces non-beneficial evaporation (E) from the area not covered by canopy 2. Reduces deep percolation 3. Water saving also comes from reduction in evaporation from fallow after harvest 4. Extent of water saving higher during initial stages of plant growth 5. Significant yield and quality improvement.
2.	Overhead (movable) sprinklers (including rain guns)	Wheat; pearl millet; sorghum; cumin; mustard; cow pea; chick pea, grasslands and pastures, tea estates	1. Reduces conveyance losses 2. Improves distribution efficiency slightly 3. Reduces deep percolation 4. Marginal yield growth
3.	Micro sprinklers	Potato; ground nut; alfalfa; garlic and onion, herbs and ornamentals	1. Reduces seepage and evaporation losses in conveyance 2. Reduces deep percolation over furrow irrigation and small border irrigation 3. Yield growth and quality improvement significant
4.	Plastic mulching	Potato; ground nut; cotton; castor; fennel; brinjal; chilly; cauliflower; cabbage; ladies finger; flowers; maize	1. Keeps complete check on the evaporation component of ET 2. Stops non-beneficial evaporation (E), kills weeds and pests 3. Extent of water saving higher over drip irrigation 4. Faster germination and significant yield growth

[2]Watermelon is often grown in intercropping with orchard crops, reducing the capital cost of drips significantly.

Sl. No	Name of water-saving and yield enhancing micro irrigation technology	Names of crops for which the technology can be used ideally	Nature of Saving in Applied Water
5.	Green houses	All vegetables, high valued fruits such as strawberry; and exotic flowers, nurseries, vegetative propagation	1. Controls the ambient temperature and humidity, 2. Checks the wind, thereby reducing transpirative demand of plant. 3. The water-saving is highest as compared to other technologies 4. Substantial yield growth, quality improvement and nutrient savings.
6.	Micro tube drips	All horticultural and plantation crops	1. Reduces non-beneficial evaporation 2. Distribution uniformity is poor and depends on number of micro tubes on a lateral

Table 2: Rate of Adoption of MI Systems during 2001-05 under various programmes

		Area Under Micro Irrigation Systems (in ha)				
Sr. No.	Name of State	2001-02	2002-03	2003-04	2004-05	Total
1	Andhra Pradesh	9117	4227	12	4200	17556
2	Arunachal Pradesh	110	100	248	500	958
3	Assam	22	16	17	350	405
4	Bihar	500	141	0	0	641
5	Chhatisgarh	444	227	0	100	771
6	Goa	70	48	0	305	423
7	Gujarat	2130	2109	1035	3650	8924
8	Haryana	226	0	236	230	692
9	Himachal Pradesh	111	85	0	0	196
10	Jammu and Kashmir	0	5	30	0	35
11	Jharkhand	179	0	0	0	179
12	Karnataka	9480	397	2635	4219	16731
13	Kerala	939	457	180	489	2065
14	Madhya Pradesh	1190	1007	200	375	2772
15	Maharashtra	14391	6875	248	844	22358
16	Manipur	10	20	25	100	155
17	Meghalya	28	0	55	60	143
18	Mizoram	0	50	20	450	520
19	Nagaland	60	55	100	50	265
20	Orissa	250	0	285	650	1185
21	Punjab	0	80	0	0	80
22	Rajasthan	1400	1000	1700	1200	5300
23	Sikkim	30	30	0	50	110
24	Tamil Nadu	814	635	25	1986	3460
25	Tripura	118	0	278	300	696
26	Uttar Pradesh	454	264	0	235	953
27	Uttaranchal	100	100	0	0	200
28	West Bengal	0	0	0	99	99
	Total	42173	17928	7329	20442	87872

Source: Task Force on Micro Irrigation, Ministry of Agriculture, Government of India

Though exact state level wise data on the spread of sprinkler systems are not available, it is found that sprinkler systems are in vogue in regions where conditions are unfavourable for traditional method of irrigation such as loose sandy soils and highly undulating fields. These areas are irrigated by wells. Farmers in other (well-irrigated) areas have also procured the system under government subsidy programme, but were using HDPE pipes for water conveyance in the field except during droughts when they use them for providing supplementary irrigation to kharif crops.

In India, sprinkler systems are mainly used for field crops such as wheat, sorghum, pearl millet, groundnut and mustard. But the use of sprinklers is often limited to certain part of the crop season when farmers face severe shortage of water in their wells. Normally, this is just before the onset of monsoon when the farmers have to sow these crops, or when there is a long dry spell during the monsoon season. Sprinkler for groundnut is common in Saurashtra in Gujarat; sprinkler for mustard is common in Khargaon district of Madhya Pradesh and Ganga Nagar district of Rajasthan. In the high ranges of Kerala and Tamil Nadu, sprinklers are used for irrigating tea and coffee plantations. However, recently, farmers have started using micro sprinklers and mini micro sprinklers for potato, groundnut and alfalfa.

3.2 Potential Contribution of Micro-irrigation Technologies in India

3.2.1 Physical impact of micro-irrigation technologies on water demand for crop production

Analyzing the potential impact of MI systems on the aggregate demand for water in crop production involves three important considerations. The first concerns the extent of coverage that can be achieved in MI system adoption at the country level. The second concerns the extent of real water saving possible with MI system adoption at the field level. The third concerns what farmers do with the water saved through MI systems, and the changes in the cropping systems associated with adoption. But, most of the past research on physical impacts of MI systems had dealt with the issue of changes in irrigation water use, crop growth and crop yield.

There is limited analysis available on the potential coverage of MI systems in India, and the water saving possible at the aggregate level. These analyses suffer from severe limitations. *First:* the analyses of potential coverage of MI systems are based on simplistic considerations of the area under crops that are amenable to MI systems, and do not take into account the range of physical, socio-economic and institutional factors that induce severe constraints to adoption of these technologies. *Second*: they do not distinguish between saving in applied water and real water saving, while the real water saving that can be achieved through MI adoption could be much lower than the saving in applied water. *Third*: there is an inherent assumption that area under irrigation remains the same, and therefore the saved water would be available for reallocation. But, in reality, it may not be so. With introduction of MI systems, farmers might change the very cropping system itself, including expansion in irrigated area. Therefore, all these assumptions result in over-estimation of the potential coverage of MI systems and the extent of water-saving possible with MI adoption. These complex questions are addressed in the subsequent sections of this paper.

3.2.1A Physical constraints and opportunities for adoption of MI Systems

Determining the potential coverage that can be achieved in MI system adoption require a systematic identification of the conditions that are favourable or un-favourable for adoption and a geographical assessment of areas where such conditions exist. Such conditions can be physical, socio-economic or institutional. These physical, socio-economic and institutional constrains in the adoption of MI systems are discussed below.

If we do not consider the difficult options of shifting to less water intensive crops and crops having higher water productivity, there are two major pre-requisites for reducing the overall demand for water in agriculture in the region. They are: i] reducing the non-beneficial evapo-transpiration from crop land; and ii] maintaining the area under irrigation. The second issue is not being dealt with here. The time-tested and widely available technology for increasing water productivity is pressurized irrigation systems such as sprinklers and drips (or trickle irrigation). (Consider removing)

Micro Irrigation adoption is very low in India. This includes even areas where the capital investment needed for creating irrigation sources is very high such as Kolar district in Karnataka, Coimbatore district in Tamil Nadu and alluvial north and central Gujarat. While, there are several constraints at the field level, which limit the adoption of this technology by the farmers, some of the very critical ones that are physical in nature are analyzed here.

First of all, MI systems need reliable daily water supply. But, nearly 41.24% of the net irrigated area in the country gets their supplies from surface sources such as canals and tanks (source: GoI, 2002). Drips and sprinklers are not conducive to flow irrigation due to two reasons. First is the mismatch between water delivery schedules followed in canal irrigation and that required for MI systems use. Normally, in surface command areas in India, farmers get their turn once in 10-15 days at flow rates ranging from 0.5 to 1 cusec. But, for drips and sprinklers to give their best, water should be applied to the crop either daily or once in two days with lower flow rates which are equal to the evapo-transpiration. This means, intermediate storage systems would be essential for farmers to use water from surface schemes for running MIs. Storage systems are also required as settling tanks for cleaning large amounts of silt contents in the canal water supplies. Second, there is a need for pumps for lifting water from the storages and running the MI systems. These two investments reduce the economic viability of MI.

Therefore, in the current situation adoption of MI would be largely limited to areas irrigated by wells. Having said that, an increasingly large number of farmers in groundwater irrigated areas manage their supplies from water purchase. This also includes areas where groundwater over-draft is not a concern like Bihar and western Orissa, and where economic access to water is a problem. It is difficult for these farmers to adopt any MI devices.

Need for pressuring devices limits the adoption of MI systems. In groundwater over-exploited areas such as north and central Gujarat, Coimbatore district in Tamil Nadu and Kolar district of Karnataka, ownership of wells mostly does not remain with individual farmers but with groups. Also, a large number of farmers have to depend on water purchase. They get water through underground pipelines at almost negligible water pressure (head). In order to use the conventional sprinkler and drip systems, high operating pressure (1.0-1.2 kg/cm^2) is required. Unless the systems are directly connected to the tube well, the required amount of “head” to run the sprinkler and drip system cannot be developed. The need for a booster pump and the high cost of energy required for pressurizing the system to run the sprinklers and drips reduce the economic viability. But, there are new MI technologies, which require very low operating head such as sub-surface irrigation systems and the micro-tube drips. Farmers who are either water buyers or share wells can store the water in small tanks, lift it to small heights to generate the required head for running the sub-surface drip system or micro tube systems.

Another important constraint is the poor quality of groundwater. Due to the high TDS level of the pumped groundwater (the TDS levels are as high as 2000 ppm (parts per million) in many parts of India where groundwater is still being used for irrigation), the conventional drippers that are exposed to sunlight get choked up due to salt deposition in the dripper perforations. The saline groundwater areas include south western Punjab, north and central Gujarat, parts of Rajasthan, and many parts of Haryana. This needs regular cleaning using mild acids like the hydrochloric acid. This is a major maintenance work, and farmers are not willing to bear the burden of carrying out this regular maintenance. However, in limited cases, rich farmers in South West Punjab use large surface tanks for storing canal water when it is available, and blend it with brackish groundwater, and use for drip irrigating *kinnow* (a citrus fruit) orchards to prevent problems of clogging.

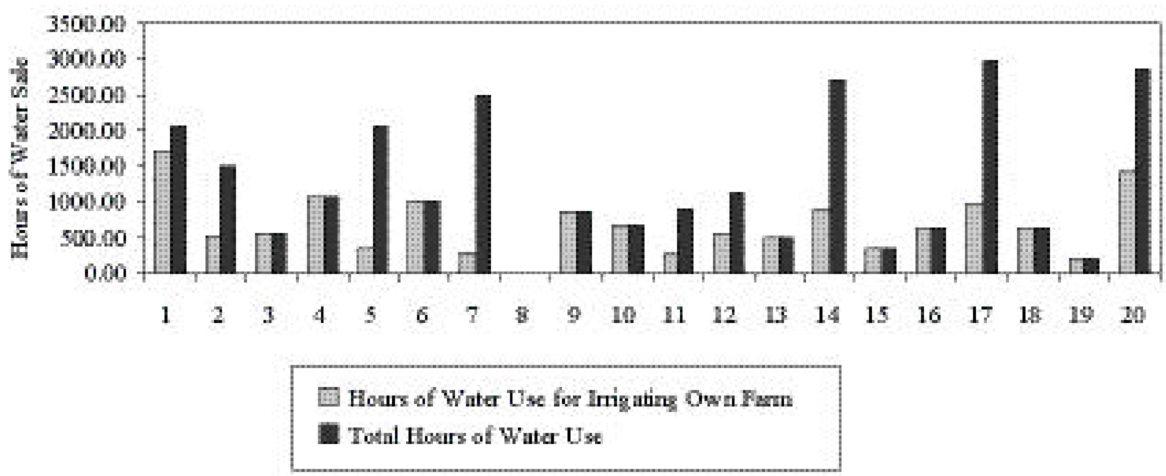
In addition to areas irrigated by groundwater, there are hilly areas of the western and eastern Ghat regions, north-western Himalayas (Himachal Pradesh, Jammu and Kashmir and Uttaranchal) and states in north-eastern hill region, where surface streams in steep slopes could be tapped for irrigating horticulture/plantation crops. Such practices are very common in the upper catchment areas of many river basins of Kerala, which are hilly. Farmers tap the water from the streams using hose pipes and connect them to sprinkler systems. The high pressure required to run the sprinkler system is obtained by elevation difference in the order of 30-40 mts. Such systems are used to irrigate banana, vegetables and other cash crops such as vanilla. With the creation of an intermediate storage, drips can irrigate crops such as coconut, aracnut and other fruit crops during the months of February to June.

Geological setting has a strong influence on MI adoption in well-irrigated areas. In hard rock areas, farmers will have strong incentive to go for MI systems. The reason is dug wells and bore wells in hard rock areas of Maharashtra, Madhya Pradesh, Tamil Nadu, Karnataka and Andhra Pradesh have very poor yield and well owners leave a part of their land fallow due to shortage of water. In most of these areas, farmers have to discontinue pumping after 2-3 hours for the wells to recuperate. When pressurized irrigation systems (drips, sprinklers) are used, the rate at which water is pumped will reduce. This gives enough opportunity time for wells to recuperate. Since, pump will eventually run for more number of hours, the same quantity of water could be pumped out, and the command area can be expanded. This factor provides a great economic incentive for farmers to go for water-saving micro irrigation systems.

3.2.1B Socio-economic and institutional constraints for MI adoption

Another major constraint in adopting conventional MI technologies is the predominant cropping pattern in the water-scarce regions. MI systems are best adaptable for horticultural crops from an economic point of view (Dhawan, 2000). The analyses presented in Table 11 and 12 also substantiate this point. Saving in input costs are not very significant, the additional investment for drips has to be offset mainly by better yield and returns (Kumar et al., 2004). But, percentage area under horticultural crops is very low in these regions, except Maharashtra[1]. Though the low cost drip irrigation systems appear to be a solution, they have low physical

Figure 1: Total Water Use Vs Own Irrigation



efficiency when used for crops in which the plant spacing is small (chilly, vegetables, groundnut and potato) (Source: IWMI research in Banaskantha). In such situations, they also score low on the economic viability. Low cost systems can be used for some of the row crops such as castor, cotton and fennel. However, to use the system for these crops, it is very important that the farmers maintain a fixed spacing between different rows and different plants. So far as maintaining the spacing between rows is concerned, farmers pay sufficient attention. But, spacing between plants is not maintained. Due to this un-even (un-favourable) field conditions, designing and installing drippers becomes extremely difficult. Therefore, for adoption of these water saving technologies, the farmers' agricultural practices need major changes.

For crops such as paddy, neither drips nor sprinkler irrigation systems are feasible. Paddy is an important crop in many arid and semi arid regions where water levels are falling. Certain studies at ICAR (Patna) have

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The total area under horticultural crops and vegetables is only 5.04 per cent of the net irrigated area in the country in 2001-02. It is highest in Maharashtra, both in percentage (19.04%) and aggregate terms (0.75 M ha).

developed Low-Energy Water Application (LEWA) systems which apply regulated water supplies to paddy and have demonstrated potential to save water. But the technology is still in its infancy and requires large scale testing before field scale adoption. Adopting suitable cropping patterns that would increase the adoptability of water saving technologies is one strategy. But, as mentioned in the beginning of the section, "crop shift" is a harder option for farmers.

The socio-economic viability of crop shifts increases with the size of the operational holding of farmers. Given that small and marginal farmers account for large percentage of the operational holders in India, the adoptability of horticultural crops by farmers in these regions cannot be high. This is because these crops need at least 3-4 years to start yielding returns, (except for pomegranate, papaya). It will be extremely difficult for these farmers to block their parcel of land for investments that do not give any returns after a season. Market is another constraint. Large-scale shift to fruit crops can lead to sharp decline in the market price of these fruits. Labour absorption is another major issue when traditional crops such as paddy, which are labour-intensive, get replaced by orchards. Orchards require less labour, it is also seasonal, and the chances for mechanization are higher.

Plot size also influences farmers' choices. Conventional MI systems will be physically and economically less feasible for smaller plots due to the fixed overhead costs of energy, and the various components of these irrigation systems such as filters, overhead tanks (Kumar, 2003).

The following equation calculates the pressure "head" required to pump water for running pressurized irrigation systems.

$$P_{req} = \frac{(P_2 + P_L)}{(w + Z)}$$

Where P_{req} is the residual pressure required at the well outlet. P_2 is the pressure required at the sprinkler nozzle or dripper and P_L is the pressure loss during conveyance of water from the tube well to the sprinklers or the drips. Z is the difference in elevation. If the sprinkler/drip systems are located at a higher elevation than the pump outlet, then 'Z' will be negative. The equation shows that the additional energy required for running the system will reduce with every additional sprinkler, the reason being that only the pressure loss increas es with increase in number of sprinklers/drip irrigated area. However, organizations like International Development Enterprises (IDE) have developed and promoted MI systems for very small landholders, which use small storage cisterns for providing the required pressure.

Poor rural infrastructure, mainly power connections to agro wells and the quality of power supply, is another major constraint for adoption of MI systems. Difficulty in obtaining power connections for farm wells, and poor quality of power supply forces farmers to use diesel pump sets for irrigating their crops. Use of diesel pump increases the cost of abstraction of well water. Regions such as Bihar, eastern UP and Orissa are examples. Here, many cash-starved farmers do not own wells, and depend on water purchased from well owners for irrigation. Drips and sprinklers are energy intensive systems, and installing such systems would mean extra capital investments for installing higher capacity pump sets as well as recurring expenses for buying diesel. These factors act as deterrents for adopting MI systems.

The current water pricing and energy pricing policies that exist in most states[4] also reduce the economic incentives for MI adoption. Due to these policies, the water-saving and energy-saving benefits from the use of MI systems do not get converted into private benefits.

Un-scientific water delivery schedules followed in surface irrigation systems, and power supply restrictions for farm sector also induce constraints for MI adoption. It is common in surface irrigation systems that while plenty of water is released for the crops for certain part of the season, in the last leg of the crop season the crops are subject to moisture stress. Poor reliability of water delivery services or lack of adherence to a standard delivery schedules and poor control over volumetric supplies force farmers to adopt crops that are less sensitive

[4]They are: 1] crop area based pricing of surface water for irrigation; 2] flat rate system of pricing of electricity or free electricity followed by many Indian states for farm sector. Only Gujarat and Orissa had partially introduced metering of electricity for farm wells.

to water stress such as paddy and sugarcane and resort to flood irrigation. Regulated power supply in agriculture is also reducing the economic incentive for adoption of MI systems that are energy-intensive. Many states including Punjab, Madhya Pradesh, Tamil Nadu, Gujarat and Karnataka had consistently reduced the duration of power supply to farm sector, due to growing power crisis. In future, this would emerge as a major impediment for large-scale MI adoption.

Poor extension services offered by concerned agencies pose another major constraint. It is not common for the extension wings of Agricultural Universities to set up demonstration of new technologies in farmers' fields. This is applicable to companies which manufacture and sell MI devices. Because of this, there is very little knowledge about MI technologies among the farmers in water-scarce regions. The existing knowledge is filled more with misconceptions. Many farmers believe that MI systems have severe limitations vis-à-vis crops for which they could be used. Another misconception is that coverage of sprinklers being circular leaves a lot of dry spots in the irrigated fields. This belief has mainly come from the experience of farmers who have used the system with improper designs.

The administration of subsidies in MI devices also works against the promotion of MI systems. In many states, the governments continue to pay the subsidy directly to the manufacturers. Many farmers purchased MI systems just to avail the subsidy benefits, and do not maintain them. The suppliers do not offer any after-sales services to the farmers and hence are not interested in ensuring quality control. The systems supplied are often of sub-standard quality. Over and above, as the amount funds available for subsidies are limited, the smarter influential farmers take benefit. On the other hand, the government officials, who come and inspect the systems installed, only check the amount of materials supplied, and work out the subsidy that has to be paid to the irrigation company. Since the manufacturers had the hassle of doing the entire documentation for obtaining the subsidy, they keep the price (without subsidy) high enough to recover their interests on capital and transaction costs.

The present institutional framework governing the use of groundwater, which puts no limit on the amount of water farmers can pump from aquifer, does not provide clear economic incentives to use water efficiently. This is particularly so for well owners, who have good sources of water supply. Examples are the Indo-Gangetic alluvium and alluvial areas of Gujarat. Though the opportunity cost of using water influences farmers' decision-making, the opportunity costs are not felt clearly. This is in spite of the prevalence of water markets[6] in these regions. The reason is that the demand for water from the water buyers and for ones own irrigation use, is much less than the number of hours for which the farmers could run their pumps[6] (see Figure 1). In such cases, the direct additional financial returns farmer gets by introducing MI systems are from the increased crop yield. This will not happen unless the farmer adopts new agronomic practices.

Due to this reason, the well owners would rather pump for extra hours to sell water to the needy farmers than trying to use water more efficiently by making substantial capital investments. The economic efficiency of water use for irrigated crops in the area even with the current inefficient practices is much higher than the price at which water is traded (Kumar and Singh, 2001).

Negative externalities in groundwater pumping pose a serious constraint for MI adoption. Well interference is very common in hard rock areas. Under such conditions, pumping by one farmer will have effect on the prospects of pumping by another farmer. Due to this reason, the efforts to cut down pumping rates by a farmer may not result in increased future availability of groundwater for the farmer. Efforts to save water from the system by an individual farmer might mean increased availability of groundwater for pumping by the neighboring farmers. Under such situations, the farmers do not have any incentive to invest in MI systems. The technical externality becomes negative externality for well irrigators in the absence of well-defined water rights in groundwater.

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[5] These are not formal water markets, but pump rental markets. Here the well owners are not confronted with the opportunity cost of tapping water from the aquifer.

[6] For instance, a survey of 19 tube well owners carried out in Daskroi taluka of Ahmedabad district showed that the total hours of pumping including that for providing irrigation services to the neighbouring farmers is in the range of 80 hours and 2930 hours. Most of them are found to be in the range of 1000 hours. But, the hours for the farmers could run the pump is as high as 3600.

3.2.1C Real Water Saving and Water Productivity Impacts of MI Systems in the Field

The real water saving impact of MI systems at the field level depends on improvements in water use efficiency. All the available data on the efficiency impact of micro irrigation systems are on application efficiency[7]. The classical definition of irrigation efficiency is the ratio of amount of water consumed by the crop to the amount of water applied. Sivanappan (1998) provides the data on application efficiencies at various stages such as conveyance efficiency, field application efficiency and soil moisture evaporation (see Table 3). These figures do not take into account two factors:1] in certain situations, water will have to be applied in excess of the ET requirements for the purpose of leaching if the irrigated soils have salts; and 2] the actual field performance in the irrigation systems is not as good as that shown in experiments and demonstrations.

In estimating water-saving, what matters is the amount of depleted water, rather than the amount of water applied. The depleted water includes moisture evaporation from the exposed soil and non-recoverable deep percolation. It would be less than the applied water so long as the un-consumed water is not lost in natural sinks like saline aquifer or swamps (Allen *et al*., 1997). This means, the application of the concept of irrigation efficiencies are no longer useful in analyzing the performance of irrigation systems, with greater understanding of agro-hydrology and appreciation of deep percolation from irrigated fields[8] as a component of the available water resources (Keller *et al*., 1996), except in situations where the groundwater is saline or deep or the unconsumed water goes into swamps.

Water use efficiency improvements through MI adoption, and therefore the field level water-saving impacts, depend on three major factors: 1] the geo-hydrological environment, including the depth to groundwater table and the nature of aquifer, whether freshwater or saline; 2] the type of crops; and 3] the agro-climate.

In regions where water table is deep and showing declining trends, MI adoption can lead to real water saving at field level. The reason is deep percolation that occurs under traditional method of irrigation, does not reach the groundwater table. This can be explained in the following way. The depth of groundwater table is in the range of 20 m to 135 m. The 20-135 m thick vadose zone holds the vertically moving water as hygroscopic water and capillary water. Some of the water from the soil profile within or below the root zone, having higher levels of moisture, also can move up due to differential hydraulic gradients (Ahmed *et al*., 2004). All this water would eventually get evaporated from the crop land after the harvest if the fallow period is significant depending, on the climate. The depth of soil below the surface from which evaporation could take place can be up to 2-3m in semi arid and arid regions (Todd, 1997). Some water in the deep vadoze zone would get sucked away by the deep-rooted trees around the farms during the non-rainy season.Since, under MI system, water is applied daily in small quantities to meet the daily crop water requirements, deep percolation is prevented.

Such regions include alluvial tracts of north and central Gujarat, central Punjab, hard rock areas of northern Karnataka, Tamil Nadu, Andhra Pradesh, Maharashtra, Madhya Pradesh and many parts of Rajasthan. Though deep percolation could be quite significant in paddy irrigation, so far no water-saving irrigation devices are being tried in paddy, though many water saving practices have evolved over time in paddy irrigation.

Nevertheless, in areas where groundwater levels are still within 20 m below ground level, the saving in applied water achieved through MI devices would mostly result in saving in pumping cost, but no real saving in water from the system. The reason is that a good share of the excess water used in irrigation under the traditional irrigation practices finally goes back to the groundwater system through return flows. It is important to note that areas with high water table coincide with areas with low level of aridity or mostly sub-humid or humid climate where evaporation losses from soil would be low even in summer months.

The real water saving that can be achieved through MI system would be high under semi arid and arid climatic conditions. This is because the non-beneficial depletion of moisture from the exposed soil could be high under such situation due to high temperature, wind speed and low humidity. Such losses would be significant during initial stages of crop growth when canopy cover is small[9].

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[7]It refers to total amount of water diverted from the source for irrigation and not the amount of water applied in the field.

[8]Deep percolation is due to the drainage below the root zone, which can find its way to perched water table or true groundwater table. Deep percolation is common in all surface methods of irrigation such as border irrigation (both leveled and unleveled small and large border), furrow irrigation and flooding.

Real water saving would be more for row crops, including orchards, cotton, fennel, castor, and many vegetables, where the spacing between plants is large. The reason is the area exposed to solar radiation and wind between plants would be large, and as a result the non-beneficial evaporation would be a major component of the total water depleted, under traditional method of irrigation. With drip irrigation, water could be directly applied to plants, preventing this loss. Such row crops are widely grown with drips and sprinklers in arid and semi arid regions of India. Examples are mulberry in Karnataka; cotton, sugarcane, banana, groundnut, coconut and vegetables in Tamil Nadu; chilly and mangoes in Andhra Pradesh; orange, banana, pomegranate, mangoes, grapes, flowers, sugarcane and vegetables in Maharashtra; cotton, mustard, rapeseed and wheat in Madhya Pradesh; oil seed crops such as cotton, groundnut, castor, mustard and fennel, and wheat, potato and alfalfa in Gujarat; mustard and chilly in Rajasthan; and wheat and potato in Punjab. Hence, the reduction in non-beneficial evaporation from soils and non-recoverable deep percolation, and hence actual water saving through micro irrigation could be in the range of 10-25% depending on the type of crops and the natural environment (soils, climate and geo-hydrology).

There are no scientific data available in India on the actual impact of MI systems on water use efficiency, which estimates the depleted water against the water consumed by the crop, or which takes into account the amount of water available for reuse from the total water applied. The figures provided by Sivanappan (1998) do not give figures of "real water saving", the extent of which would be determined by the climate (arid, semi arid or sub-humid or humid), depth to groundwater table and groundwater quality, and the amount of water available for deep percolation.

Table 3: Relative Irrigation Efficiencies (per cent) under Different Methods of Irrigation

Irrigation Efficiencies	Method of Irrigation		
Conveyance Efficiency[1]	Surface 40-50 (canal) 60-70 (well)	Sprinkler	Drip
Application Efficiency[10]	40-70	60-80	90
Surface water moisture evaporation	30-40	30-40	20-25
Overall efficiency	30-35	50-70	80-90

Source: Sivanappan (1997)

[1] This is for open channels

There is effectively no research in India quantifying the real water saving and water productivity impacts of water saving irrigation technologies on various crops, at the field level. An extensive review of literature shows that all the data on water-saving are based on applied water, and within that more reliable ones are on experimental farms, for limited number of crops and system types and for a few locations. Table 4 presents experimental data on water-saving, yield rise and water use efficiency improvements with drip irrigation over flood irrigation in several crops from different research stations across India. The reduction in water consumption varies from a mere 12% for ash gourd and bottle gourd to 81% for lemon.

[9]For instance, direct dry seeded rice in wet season and direct wet seeded rice in dry season were found to be effective ways of saving water in rice irrigation over transplanted rice (Tabbal *et al*., 2002). Similarly, large amount of research in India has demonstrated the benefits of applying irrigation after 2-3 days of disappearance of applied and ponded water. Field studies conducted on System of Rice Intensification (SRI) also showed significant reduction in applied water use owing to reduction in the duration for which the field remains under submerged conditions (Satyanarayana, 2004; Tiyagarajan, 2005). Majority of this reduction could have possibly come from reduction in deep percolation of water from the paddy field. However, the area under SRI, aerobic rice and other methods of improved irrigation is still very small in India.

[10]Here, application efficiency is defined as the ratio of volume of water retained in the RZ at application against the total water applied.

As seen from the data, some of the figures on water saving are quite high. But, it is important to remember here that the condition of flood irrigation system chosen for comparison influences the findings on water saving and yield improvements in DMI (drip method of irrigation). Poorly managed flood irrigation systems used for comparison could significantly affect the result in favour of DMI. However, to obtain high efficiencies, surface methods (furrow, border, and basin) generally demand operating skills and a high degree of flexibility in water supply. In contrast, much of the complexity of drip and sprinkler irrigation systems is in their design rather than their operation, and they can more easily be operated (but are not always) with low losses. Generally, the natural environment imposes constraints on realistically achievable efficiency levels (Carter *et al.*, 1999),[11] and therefore in what environments the comparisons are made is also important. With the same technology, and with the same crop, the water saving and yield impacts of these irrigation technologies would depend on the agro climate.

One major limitation of the database is that they are generated for a single location. Another limitation is that it compares DMI with one traditional method only. But, the extent of field level water saving through DMI would be heavily influenced by the conventional irrigation method practiced for that crop in the region under consideration, and the precision irrigation followed in drip irrigation. Flooding is just one of the many traditional irrigation methods used by Indian farmers. Its use is generally limited to canal irrigated fields, and fields irrigated by wells in canal command areas due to high flow rates from canals. Well irrigators generally use other methods viz., small border irrigation, trench irrigation and furrow irrigation. On-farm efficiencies are much higher under furrow, trench and small border irrigation as compared to flooding. Another limitation is that data obtained from experimental farms are for ideal conditions, and using such data can lead to over-estimation of field level water saving and water use efficiency impacts of DMI. The reason is it is difficult to simulate the ideal conditional of experimental farms in farmers' fields.

The rest of the data on field level water savings and yield improvements through MI systems are from socio-economic studies based on respondent surveys involving adopters and non-adopters. The results from such studies are summarized in Table 5. The data on water saving are arrived at using figures of total applied water. The available data from the experimental farms do not enable analysis of reduction in depleted water under various treatments. Based on the earlier discussions, it is reasonable to assume that for traditional methods of irrigation, the "applied water" would be very close to the depleted water for row crops, under semi arid and arid climatic conditions, there are no hard empirical data obtained from experiments to prove this. Here, deep percolation is one unknown parameter.

While MI systems are expected to have likely impact on deep percolation from the fields, such deep percolation can be treated as loss into the sink because of the following reasons: 1] drip irrigation is normally used in well-irrigated fields; 2] the amount of water percolating in non-paddy irrigated fields would normally be low (source: based on Ahmed *et al*., 2004;) especially for well irrigation, as the dosage per watering is generally low ; 3] depth of vadoze zone in which the percolating water could be held as hygroscopic water or capillary water would be high in arid and semi arid areas which depend on groundwater; and, 4] part of the water going into the vadoze zone can get lost in soil evaporation during fallow period (based on Todd, 1997). Hence, applied water saving which the available literature refer to can be treated as real water saving.

But, these studies are not complete in themselves, as they cover only a few crops, and a few MI devices. Also, these studies have limitations. First, they are mostly based on data obtained from respondent surveys, which capture relative benefits of the technology from the farmers' perspective. Second, they are also likely to be influenced by respondents' bias. In order to understand the extent to which the water productivity of crops could be enhanced through MI technologies, it is crucial to get realistic data on potential changes in irrigation water use and crop yield, the two determinants of water productivity, with different technologies.

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[11]Soil types, climate and hydrology can affect water losses. Surface irrigation is likely to be more efficient on vertisols than sandy soils. Undulating or sloping land may dictate the use of drip or sprinkler irrigation which can then be managed with less water loss than surface techniques. Unpredictability complicates management and normally reduces efficiency. Total irrigation is easier to schedule and manage than supplementary irrigation because of the unpredictability of natural rainfall (Carter et al., 1999).

Field experiments were conducted in Banaskantha district of Gujarat with different MI devices on various crops to analyze the impact of the technology on irrigation water use, crop yield and water productivity. Banaskantha district falls in semi arid to arid climatic conditions. The mean annual rainfall for the location (Palanpur) was 682mm (source: authors' own analysis based on data provided by Gujarat Agriculture University, Anand). The annual reference evapo-transpiration (ET_0) for the nearest location (Radhanpur) was estimated to be 1750mm. 32% of this evapo-transpirative demand is during the four months of July-October when the region receives monsoon rains (source: Indian Meteorological Department, Ahmedabad as cited in Figure 6 of Kumar, 2002b: page 17). The soil type in the area varies from sandy to sandy loam and loamy sand.

Table 4: Saving in Applied Water and Productivity Gains through Drip Irrigation

Name of the crops	Water consumption (or application?) (mm/ha)		Yield (ton/ha)		Water saving over FMI (%)	Yield increase overFMI (%)	Water consumption per ton of yield (mm/ton)	
Vegetables	FMI	DMI	FMI	DMI			FMI	DMI
Ash gourd	840	740	10.84	12.03	12	12	77.49	61.51
Bottle gourd	840	740	38.01	55.79	12	47	22.09	13.26
Brinjal	900	420	28.00	32.00	53	14	32.14	13.13
Beet root	857	177	4.57	4.89	79	7	187.53	36.20
Sweet potato	631	252	4.24	5.89	61	40	148.82	42.78
Potato	200	200	23.57	34.42	Nil	46	8.49	5.81
Lady's finger	535	86	10.00	11.31	84	13	53.50	7.60
Onion	602	451	9.30	12.20	25	31	64.73	36.97
Radish	464	108	1.05	1.19	77	13	441.90	90.76
Tomato	498	107	6.18	8.87	79	43	80.58	12.06
Chilly	1097	417	4.23	6.09	62	44	259.34	68.47
Ridge gourd	420	172	17.13	20.00	59	17	24.52	8.60
Cabbage	660	267	19.58	20.00	60	2	33.71	13.35
Cauliflower	389	255	8.33	11.59	34	39	46.67	22.00
Fruit Crops								
Papaya	2285	734	13.00	23.00	68	77	175.77	31.91
Banana	1760	970	57.50	87.50	45	52	30.61	11.09
Grapes	532	278	26.40	32.50	48	23	20.15	8.55
Lemon	42	8	1.88	2.52	81	35	22.34	3.17
Watermelon	800	800	29.47	88.23	Nil	179	27.15	9.07
Sweet Lime*	1660	640	100.0	150.00	61	50	16.60	4.27
Pomegranate*	1440	785	55.00	109.00	45	98	26.18	7.20
Other Crops								
Sugarcane	2150	940	128.00	170.00	65	33	16.79	5.53
Cotton	856	302	2.60	3.26	60	25	329.23	92.64
Groundnut	500	300	1.71	2.84	40	66	292.40	105.63

*: Yield in 1000 numbers;

Source: INCID (1994) and NCPA (1990) as cited in Narayanamoorthy (2004): pp 122

Note: FMI and DMI refer to flood method of irrigation and Drip Method of Irrigation, respectively.

Table 5: Results available from past studies on water saving and yield impacts of drip irrigation

Name of researchers	Location	Nature of study	Results on	
			Saving in Applied Water	Crop Yield
Jadhav *et al.* (1990)	Haryana	Socio-economic	31 per cent saving in water use in tomato	Yield increase by 50 %
Hapase *et al.* (1992)	Maharashtra	Socio-economic	50-55 per cent saving in water in sugarcane crop	Yield increase in the range of 12-37%
Muralidharan and others (1994)	Kolar, Karnataka	Socio-economic	Water-saving benefits highlighted, not quantified	
Narayanamoorthy (1996)	Nashik, Maharashtra	Socio-economic (respondent survey)	41 per cent water saving for banana and 59 per cent for grapes	Productivity higher under DMI for both crops
Reddy and Thimmegowda (1997)	Bangalore, Agricultural University Research Station	Experimental farm measurements	Water-saving benefits not quantified	Seed cotton yield increased by 13% under drip tap; 16% under emitter drip
Reddy and Thimmegowda (1997)	Bangalore, Agricultural University Research Station	Experimental farm measurements	Water-saving benefits not quantified	Seed cotton yield increased by 13% under drip tap; 16% under emitter drip Ratoon yield by 3% under drip tape; and 6% under emitter drip
Dahake and others (1998)	Akola district of Maharashtra (Orange)	Socio-economic survey	Uniform distribution and conservation of water in orchards	
R. L. Shiyani and others (1999)	Four districts of Saurashtra in Gujarat viz., Junagadh, Rajkot, Amreli and Bhavnagar (Cotton)	Socio-economic survey	Socio-economic survey Water saving not quantified; but estimated reduction in irrigation cost as varying from 25% to 51%; increase in irrigation cost in Bhavnagar	Yield enhancement in cotton in all districts, averaging 22%
Palanisamy and others (2002)	Coimbatore (Coconut)	Socio-economic survey	50 % water saving in coconut	20-30 per cent increase in coconut yield
Kumar and other (2004)	Banaskantha, Gujarat (Alfalfa)	Techno-economic evaluation of drips in demo farms of alfalfa	Reduction in water application in the range of 7-43 per cent	Yield increase in the range of 5-10 per cent

Name of researchers	Location	Nature of study	Results on	
			Saving in Applied Water	Crop Yield
Kumar, Singh, Singh and Shiyani (2004)	Four districts in Gujarat (several crops)	Socio-economic survey	Extent of water saving varies from crop to crop and from system to system	Yield increase in all crops; but variation in yield benefits across crops
Waykar and others (2003)	Ahmednagar district of Maharashtra (Sugarcane)	Socio-economic survey	Data on water-saving not available	Higher yield of sugarcane (up to 27%) for adopters of drip systems.

Source: Synthesis of various studies by the authors

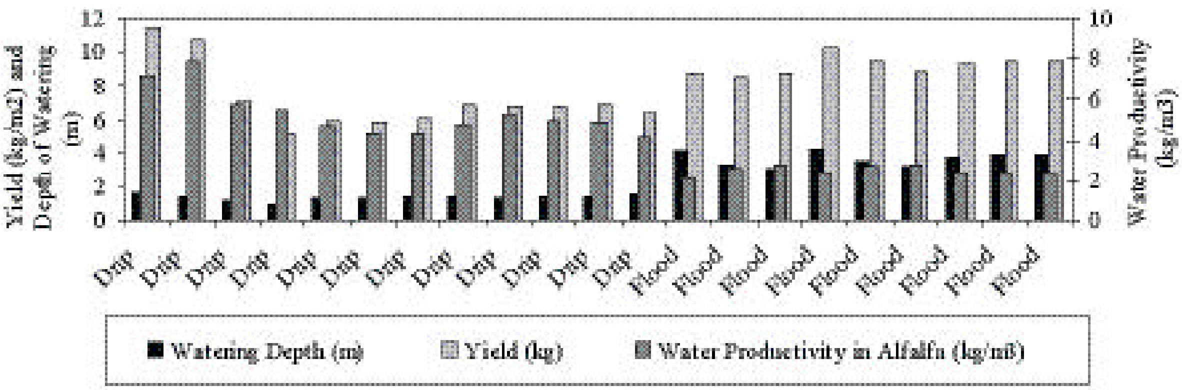
The crops covered are: alfalfa, castor, groundnut and potato. The technologies used are: inline drip system for alfalfa; micro tube drip with and without plastic and organic mulching, and flooding with and without plastic/organic mulching; micro tubes and inline drippers in groundnut; and inline drippers and micro tubes in potato. The results from these experiments are presented in Table 6-9.

The treatments used for alfalfa are: different spacing of drippers without changing the water delivery through drippers (30cm*40cm in F1 to 50cm*40cm in F4); maintaining the same spacing of drippers (30cm*30cm) with different intensities of daily irrigation (G1 to G4); maintaining same spacing of drippers with different intensities of irrigation, and with watering on alternate days; small level border irrigation with different intensities and with various irrigation schedules (from an average of 7-8 days in winter to 5 days in summer to an average of 6 days in winter to 4 days in summer). FYM was applied in all the plots in equal dozes, and no chemical fertilizers were used. The volume of water applied in the field was measured using water meters each time when irrigation is done, and output is weighted each time harvest/cutting is done.

The results are presented in Figure 2. It shows that the yield is highest for plot with a dripper spacing of 30 cm* 40 cm (11.36 Kg./m^2) of green matter, followed by one with a spacing of 35cm*40 cm (10.71 Kg./m^2). But, water productivity was highest (7.8 Kg./m^3 of water) for the plot which recorded second highest yield (F_2). Therefore, the highest yield corresponds to a depth of application of 1.6 m, while highest water productivity corresponds to a depth of 1.37 m. With flood irrigation, the yield values were highest for treatment I_5 in which the amount of water applied was 4.3 m. Though these are very high figures for small border irrigation, it can be attributed to sandy soils. Here, I1 is a case of over-irrigation with very heavy doses of irrigation (139 mm) and can be discarded. The figures are relevant since with such high dozes of irrigation no field run off was generated, meaning there are chances for farmers to actually apply such high doses in sandy soils under well irrigation.

The yield figure almost touched that obtained with daily irrigation through drips (F_1 and F_2). But, the amount of water applied was far higher than that under F type treatments-almost 3 times in most cases. The water productivity values were in the range of 1.47 Kg./m^3 and 2.79 Kg./m^3, which were only 20-30% of that obtained with drip irrigation under F_2 treatment. The results show that with drip irrigation, the water productivity could be enhanced significantly in alfalfa without compromising on the yield. As for economic viability, even if we compare the drip irrigated plots with some of the best plots under flood irrigation, the reduction in water use is substantial, with modest improvements in yield. Therefore, when water availability becomes a constraint, drip for alfalfa would be economically viable under a lateral spacing of 30cm*40 cm. This is because, one of the earlier analysis with similar type of drip system on alfalfa showed that even with 10% increase in yield, and 45% reduction in water use, drips could be economically viable, when the social benefits of water saving are taken into account. In this case, reduction in water use is much higher when F1 and F2 are compared with any of the flood-irrigation plots. Increase in yield is 10% when F2 is compared against the best flood irrigated plot, and much higher than 10% when compared against other flood-irrigated plots.

Figure 2: Impact of Drip on Applied Water Productivity in Alfalfa



The results (I_1 to I_{10}) also show that there are significant variations in water productivity levels of alfalfa under flood irrigation with changing irrigation intensity. Highest yield was obtained under second highest level of water application (4.33 m over the full crop year). Highest water productivity (2.79 Kg./m^3) was obtained with the lowest level of irrigation (3.15 m). The lowest water productivity (1.47 Kg./m^3) was obtained under highest level of irrigation (6.0 m).

Experiments carried out with micro tube drips with plastic and organic mulching and micro tubes with broad furrows as the control in Manka village of Vadgam in Banaskantha. There were four treatments followed. In the first three treatments, watering was done daily with daily irrigation water requirement estimated roughly on basis of the crop water requirement (K_c*ET_0), and daily dosage was adjusted on the basis of the field observations of soil moisture conditions. In the fourth case, the irrigation water dosage was determined by making provision for evaporative losses from the exposed soil in the crop land and deep percolation losses. The scheduling was same as that practiced in the area for castor for traditional method. While a total of 96 watering were done with C_1, C_2 and C_3, irrigation was applied nine times under C_4. The results showed that water application rate was lowest when micro tube drips were used with plastic mulching (treatment C_1), followed by micro tube with organic mulch (treatment C_2). The water application rate was highest for broad furrow treatment (C_4). The yield was highest for C_1, followed by C_4. The water productivity was highest for C_1, and second highest for C_2. The difference in water productivity was 100% between the first and the last treatment.

Table 6: Impact of Drip Irrigation on Applied Water, Yield and Applied Water Productivity in Castor in Manka

Plot No.	Method of Irrigation	Agro-nomic Practices	Plot Size (m^2)	No.of Watering	Water Application Rate (mm/ irrigation)	Per Sq. Meter Area		
						Water use (m^3)	Production (Kg.)	Water Productivity (Kg./m^3)
C - 1	Micro-tube	P M	1110	96	2.09	0.201	0.135	0.67
C - 2	Micro-tube	O M	1110	96	2.35	0.225	0.099	0.44
C - 3	Micro-tube		1110	96	3.14	0.302	0.113	0.37
C - 4	Flooding		1110	9	40.64	0.366	0.126	0. 34

PM = Plastic Mulching; OM = Organic Mulching
Source: Authors' own analysis

Experiments conducted on groundwater with inline drip systems and micro tube drips showed highest level of reduction in applied water use in case of inline drippers when compared against border irrigation. The treatment included daily application of water to the plot through inline drippers and micro tube drips. The fertilizer doses were same in all the plots which were of the same size. The reduction in water dosage was nearly 18 cm, while the yield was higher by 0.013 Kg./m^2, with a net effect on water productivity in the order of 0.18 Kg./m^3 of water (see Table 7). The micro tube irrigated plot gave same yield as that of furrow irrigated plot, but the applied water was less with micro tube. The study shows that inline drippers are physically more efficient than furrow method and inline drip irrigation.

Table 7: Impact of Drip Irrigation on Applied Water, Yield and Applied Water Productivity in Groundnut (Kumbhasan)

Plot No.	Method of Irrigation	Plot Size (m^2)	No. of Watering	Water Application Rate (mm/ irrigation)	Per Sq. Meter Area		
					Water use (m^3)	Production (Kg.)	Water Productivity (Kg./m^3)
G - 1	Inline Drip	192	49	6.54	0.320	0.130	0.41
G - 2	Micro-tube	192	49	7.05	0.345	0.117	0.34
G - 3	Furrows	192	8	62.85	0.503	0.117	0.23

Source: Authors' own analysis

Another interesting experiment was done with different types of MI devices to understand the physical productivity of applied irrigation water in potato. In this experiment, five different types of MI devices were used, viz., inline drippers; easy drips (or drip systems with flexible laterals having a thickness ranging from 125 microns to 500 microns and have perforations instead of drippers to emit water); micro tube drips; micro sprinklers; and mini sprinklers. The results are presented in Table 8. It can be seen that the yield and physical productivity of water is highest for field irrigated with micro sprinklers, followed by mini sprinklers. This is in spite of the fact that the water dosage was more than double in the case of treatments P4 and P5.

On the basis of the values of irrigation dosage and the corresponding yield and water productivity values under different treatments, one can infer that water dosage was much lower than required in the case of inline drip, easy drip and micro tube drip irrigated plots, resulting in water stress and significant yield losses. Also, another inference is that in all the treatments, water dosage was in the ascending part of the yield and water productivity response curves for irrigation water application, which also means that with higher dosage of irrigation, the chances for getting higher yield are higher. It can be seen that with micro tubes, though the amount of water applied was same as that with inline drips (P1), the yield (0.148 Kg./m^2) was much lower than that with P1. This could be due to poor distribution efficiency obtained with micro tubes.

Table 8: Impact of Drip Irrigation on Applied Water, Yield and Applied Water Productivity in Potato (Manka)

Plot No.	Method of Irrigation	Plot Size (m^2)	WST (cm)	No.of Watering	Water Application Rate (mm/ irrigation)	Per Sq. Meter Area		
						Water use (m^3)	Production (Kg.)	Water Productivity (Kg./m^3)
P - 1	Inline drip	304	52.5 x 30	56	7.50	0.420	0.375	0.893
P - 2	Easy drip	304	52.5 x 30	56	7.50	0.420	0.411	0.979
P - 3	Micro-tube drip	304	52.5 x 30	56	7.50	0.420	0.148	0.352
P - 4	Micro-Sprinkler	304	310 x 290	59	15.96	0.942	1.316	1.397
P - 5	Mini-Sprinkler	304	730 x 720	59	15.96	0.942	0.905	0.961

Source: Authors' own analysis

3.2.1D Potential aggregate impact of MI systems on water use for crop production

There is debate about the extent of water saving at system and basin level due to the widespread adoption of MI systems. This concerns: 1] whether there is real water saving in the first place, and 2] what users do with the saved water. We have addressed the first question in the earlier section. As regards the second question, many scholars believe that the aggregate impact of drips on water use would be similar to that on water use in unit area of land. While several others believe that with reduction in water applied per unit area of land, the farmers would divert the saved water for expanding the area under irrigation, subject to favourable conditions with respect to water and equipment availability, and power supplies for pumping water (Kumar, 2002),[12] and therefore the net effect of adoption of micro irrigation systems on water use could insignificant at the system level. At the same time, there are others who believe that with adoption of WSTs, there is a greater threat of depletion of water resources, as in the long run, the return flows from irrigated fields would decline, while area under irrigation would increase under WSTs.

These arguments have, however, missed certain critical variables that influence farmers' decision making with regard to area to be put under irrigated production, and the aggregate water used for irrigation. They are: groundwater availability vis-à-vis power supply availability; crops chosen; and amount of land and finances available for intensifying cultivation. The most important factor is the overall availability of groundwater in an area.

If power supply restrictions limit pumping of groundwater by farmers, then it is very unlikely that adoption of conventional WSTs would help farmers expand their area under irrigation. In the states of Punjab, Gujarat, Karnataka and Madhya Pradesh, power supply to agriculture sector is only for limited hours (GoI, 2002). It acts as a constraint in expanding the irrigated area, or increasing irrigation intensity, in those areas where groundwater availability and demand is more than what the restricted power supply can pump.

Since the available power supply is fully utilized during winter and summer seasons, farmers will be able to just irrigate the existing command with MI system. This is because the well discharge would drop when the sprinkler and drip systems connected to the well outlet start running, owing to increase in pressure developed in the system (please see equation below). In other words, the energy required to pump out and deliver a unit volume of groundwater increases with the introduction of MI system. The only way to overcome this is to install a booster pump for running the MI system. As electricity charges are based on connected load, farmers have least incentive to do this.

$$Q = \frac{\beta * 100 * \eta}{H}$$

Where, "BHP" is pump power in kilowatt/sec, "H" is the total head, "Q" is the discharge. ? = combined electrical and hydraulic efficiency of pump set.

Such outcomes are expected in the alluvial areas of north Gujarat and Punjab. In this area, even in situations of availability of extra land, it won't be possible for farmers to expand the area under irrigated crops due to restrictions on power supply.

The other factor is the lack of availability of extra arable land for cultivation. This is applicable to areas where land use and irrigation intensity is already high. Example is central Punjab. But, farmer might still adopt water-saving technologies for cash crops to raise yields or for newly introduced high-valued crops to increase their profitability. So, in such situations, adoption would result in reduction in aggregate water demand.

On the other hand, if the availability of water in wells is less than what the available power supply can abstract, with adoption of micro irrigation systems, the farmers are likely to expand irrigated area. This is the situation in most of the hard rock areas of peninsular India, central India and Saurashtra. Due to limited groundwater potential and over-exploitation, well water is very scarce in these areas. The available power supply is

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[12]If power supply is more than what is required to pump the available water from wells, then water saving can lead to expansion in irrigated area. Whereas, if power supply is less than what is required to pump the available water from wells, then water saving per unit area cannot result in area expansion (Kumar, 2002).

more than what is needed to abstract the water in the wells. Hence, farmers have strong economic incentive to go for MI systems other than yield enhancement (Dhawan, 2000). The reason is that the saved water could be used to expand the irrigated area and improve the economics of irrigated farming. In Michael region of central India, for instance, farmers use low cost drips to give pre sowing irrigations to cotton, before monsoon, when there is extreme scarcity of groundwater. This helps them grow cotton in larger area as water availability improves after the monsoon (Verma *et al*., 2005). In this case, there is no water saving at the aquifer level.

The third factor is the crops chosen. Often MI technologies follow a set cropping pattern. All the areas in the country where adoption of drip irrigation systems has increased, orchard crops are the most preferred crops (Dhawan, 2000; Narayanamoorthy, 2004b). Therefore, while farmers adopt MI systems, the crops also change, normally from field crops to fruits.[13] While for many fruit crops, the gestation period is very large extending from 3-10 years (for instance, citrus, orange and mango), for many others like grapes, pomegranate and banana, it is quite short extending from one to two years. Also, farmers can go for intercropping of some vegetables and watermelon, which reduces their financial burden of establishing the orchards. This flexibility enables small and marginal farmers also to adopt MI systems, as found in north Gujarat and Jalgaon and Nasik districts of Maharashtra.

Access to credit and subsidy further increases MI adoption among small and marginal farmers. The irrigation water requirement of the cropping system consisting of field crops such as paddy, wheat, pearl millet/ sorghum combinations is much higher than that of fruit crops such as pomegranate, gooseberry, sapota and lemon. Also for other orchard crops such as mango, the irrigation water requirements during the initial years of growth would be much less than that of these field crops. Therefore, even with expansion in cropped area, the aggregate water use would drop. Only in rare situations, the system design for one crop is adaptable for another crop. For example: the micro sprinklers that are used for winter potato, can also be used to irrigate summer ground nut and hence farmers opt for that crop.

Synthesizing, there is very little data across agro-climatic conditions on the yield impacts of micro irrigation systems for the same crop. The research is heavily skewed towards drip irrigation systems, and there is hardly any data on the economics of other WSTs. As we have seen early, for a given crop, the yield as well as water-saving benefits of MI system can change across systems, as can the capital costs. Also, it can change across crops. But, the research is also heavily skewed towards orchard crops (banana, sugarcane and cotton). These crops still occupy a small percentage of the irrigated area in the country. Further, these economic analyses were not contextualized for the socioeconomic and institutional environment for which they were performed. The socio-economic and institutional environments determine the extent to which various physical benefits get translated into private and economic benefits. We would explain it in the subsequent paragraphs.

Normally, it has been found that drip irrigation is economically viable for horticultural crops and orchards such as banana, grapes, orange, coconut, and sugarcane (Dhawan, 2000: pp 3775; Sivanappan, 1994; Narayanamoorthy, 2003).

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[13] Farmers bring about significant changes in the cropping systems of farmers with the adoption of drips. When drips are adopted for orchards, farmers permanently abandon cultivation of traditional crops such as paddy and wheat. A most recent example is Nalgonda district in Andhra. Farmers generally start with small areas under orchards and install drips. After recovering the initial costs, the general tendency of farmers is to bring the entire cultivated land under orchards, and put them under drip irrigation. This is because orchards require special care and attention and putting the entire land under orchards makes farm-management decisions easier. However, the same tendency of area expansion is not seen when MI systems are used for other cash crops such as cotton and sugarcane.

In the case of cotton, it is difficult for farmers to take up any crop that can be irrigated with drips after the harvest in the end of winter. This is due to the lack of flexibility in the design of the conventional MI systems. Due to the high capital cost, it is best suited to permanent plantings or crops having roughly the same planting space as frequent removal and rolling back can cause damage to online drips. Exceptions are porous pipes used for sub-surface irrigation. In the cotton growing areas, farmers normally roll back the system and cultivate the traditional crops in summer only if water is available. But, early sowing of cotton is found to be common among farmers who have installed drip irrigation, as they are able to manage their pre-sowing irrigation with very little water available from wells (Verma *et al*., 2004). With improved planting patterns (paired rows, pit system) farmers install almost permanent drip systems for sugarcane crop.

Table 9: Results available from past studies on economic viability of drip and sprinkler irrigation

Name of researchers	Location	Nature of study	Results on	
			Economic Viability	Remarks
Jadhav *et al.* (1990)	Pusa, Haryana	Socio-economic	5.16 and 2.96 for drip and furrow method, respectively, in tomato	
Muralidharan and others (1994)	Kolar, Karnataka	Socio-economic	B-C ratio not as good as in furrow irrigation for mulberry crop.	But, B-C ratio did not take into account the price at which water is traded in the region
Narayanamoorthy (1996)	Nashik, Maharashtra	Socio-economic (respondent survey)	Incremental return was Rs. 32400/ha in banana and Rs. 50180/ha in grapes. Reduction in cost of cultivation was Rs. 1300/ha in banana and Rs. 13400/ha in grapes	B-C analysis was based on direct costs and direct benefits and not based on incremental returns against incremental cost of drips
Narayanamoorthy (1997)	Nashik, Maharashtra	Socio-economic (respondent survey)	B-C Ratio ranged from 2.07 to 2.36 for banana and 1.48 to 1.80 for grapes with varying discounting rates	Do
Shivanappan (1994)	Tamil Nadu	Physical and Socio-economic	B-C Ratio ranged from 1.3 for sugarcane to 11.5 for grapes. The B-C ratio improved when the benefits of water saving was reckoned with	The incremental benefits calculated for the scenario of irrigated area expansion did not include the cost of establishing the crops in case of orchards
Reddy and Thimmegowda (1997)	Bangalore, Agricultural University Research Station	Experimental farm measurements	Average establishment cost was Rs.92522/ha for emitter drip irrigation, and Rs. 57482/ha for turbo tape. Turbo tape drip irrigation was found more profitable than emitter drip irrigation as indicated.	The pay back period was three years for turbo tape drip and five years for emitter drip irrigation for the main crop.

Name of researchers	Location	Nature of study	Results on	
			Economic Viability	Remarks
R. L. Shiyani and others (1999)	Four districts of Saurashtra in Gujarat viz., Junagadh, Rajkot, Amreli and Bhavnagar (Cotton)	Socio-economic survey	Significant differences in cost-B and cost-C between drip adopters and the farmers using surface method of irrigation. The major advantages of drip system over conventional method were: higher yield, higher profit, rise in labour productivity and reduction in unit cost of production	Other advantages of drip system included saving in water, reduction in weeding and labour cost, suitability for un-leveled and stony soils, increase in water use efficiency, decline in diseases and pests incidence and improvement in the quality of product
Palanisamy and others (2002)	Coimbatore, Tamil Nadu (Coconut)	Economic performance of drip irrigation	Aditional cost of drips in coconut cultivation was Rs. 31,165/ha. The cost of cultivation went up by 19% in drip-irrigated coconut. The financial viability of drip irrigation system showed more than 30 per cent modified internal rate of return in the water scarcity condition.	Reasons for improved financial viability were: higher price of coconut, 20 to 30 % increase in yield; increased fertilizer use efficiency; reduction in expenditure on plant protection chemicals; 50% water saving; and labour saving to the tune of Rs. 3000/ha.
Luhach et al. (2003)	Haryana	Socio-economic survey of sprinklers adoption in wheat	Average net returns per ha from sprinkler irrigation was found to be 19.53% higher than that for pump irrigation. On an average, the net present value of sprinkler was found to be Rs. 7970, benefit-cost ratio was 1.97, and the internal rate of return was 17%	

Source: Synthesis of various studies by the authors

The reason for this is that the crops are high valued and even a marginal increase in yield results in significant rise in value of crop output. Dhawan (2000) argues that higher value of crop output is realised also from improved price realization due to quality improvements on one hand and early arrival of the drip-irrigated crop in the market on the other. The same need not be true for other cash crops, and field crops.

3.2.2 Economic impacts of MI Systems

There is enormous amount of research-based literature showing the positive economic impacts of water-saving irrigation devices. Many research studies available from India during the past one decade quantified economic benefits from drips. They are summarized in Table 6 cant see.

For instance, the income benefit due to yield improvement depends on the type of crop. For cereals, it cannot be significant. A 10% rise in yield would result in an incremental gain of 400-500 kg of wheat or Rs. 3000-Rs.3750/ha of irrigated wheat. At the same time, a 10% rise in yield of pomegranate, whose minimum yield is 60000 kg per ha per year, would result in an incremental gain of 6000 kg/ha or Rs.90000/ha. Besides the incremental value of outputs, an important factor which influences the economic performance of drip system is the cost of installation of the system.

From the point of view of deciding investment priorities including the provision of subsidies, it is important to know the social benefits from drip irrigation. As Dhawan (2000) notes, cost-benefit analyses, which do not take into account social costs and benefits, are on weak conceptual footing as the government subsidies in micro irrigation systems are based on the premise that they have positive externality effect in terms of water saving. In areas, where available water in wells is extremely limited, it is logical to take water-saving benefits and convert the same in monetary terms based on market price or in terms of additional area that can be irrigated. Same is the case with energy saving. But the same methodology cannot be applied to areas where access to water is not a limiting factor for enhancing the area under irrigation, or energy is not a scarce resource. But, such analysis are absent in India.

Given the range of variables - physical, socio-economic and financial - that affect the costs and returns from crops irrigated by MI systems, it is important to carry out comprehensive analysis taking into account all these variables, across situations where at least the physical, socio-economic conditions change. Now, we examine how these variables change under different situations.

As regards water saving, in many areas, the well owners are not confronted with the opportunity cost of wasting water. Hence, water saving does not result in any private gains. Where as in some hard rock areas like Kolar district in Karnataka, the amount of water that farmer can pump from the well is limited by the geo-hydrology. The price at which water is sold is also high in such areas (Deepak *et al*., 2005), as is the opportunity cost of using water. Hence, the amount of water saved would mean income saving for the adopters.

As regards benefit due to energy-saving, it is applicable to certain MI devices, especially low pressure systems and gravity systems such as drip tapes, micro tube drips and easy drips. But, farmers of many water-scarce regions are not confronted with marginal cost of using energy. Hence, for them energy saving does not result in any private gain. But, from a macro economic perspective, if one wants to examine the economic viability of the system, it is important to consider the full cost of supplying electricity to the farms while evaluating the economics of irrigation using the system. Also, we consider the price at which water is traded in the market for irrigation (ranging from Rs.1.5/m3 to Rs.2.5/m3 in north Gujarat to Rs.6/m3 in Kolar) as the economic value of water[14] then any saving in water resulting from drip use can be treated as an economic gain. The real economic cost of pumping water ranges from Rs. 1.5/m3 in north Gujarat to Rs. 2/m3 in Kolar district.

The private income benefit due to water saving is applicable to only those who purchase water on hourly basis. Dhawan (2000) cautions that over-assessment of private benefits are possible in certain situations where return flows from conventional irrigation are significant (Dhawan, 2000). But in regions where reduction

[14]Though the actual economic value of the groundwater would be equal to the economic surplus generated by the use of that water for irrigation, which would vary according to the type of crops farmers grow, this would be a reasonable assumption that can lead to more conservative estimates of economic benefits of water saving.

in deep percolation means real water saving, it leads to private benefits. Here, for water buyers, the private income gain from the use of drip or sprinkler system depends on the price at which water is purchased (volumetric) and the reduction in water use achieved. There could be significant social benefits due to water saving in water scarce regions, owing to the reduced stress on water resources (Dhawan, 2000), resulting from reduced pumping. In situations like north Gujarat, such social benefits could not be over-emphasised.

As regards the cost, the capital costs could vary widely depending on the crop. For widely spaced crops (mango, sapota, orange and gooseberry) the cost could be relatively low due to low density of laterals and drippers. For closely spaced crops such as pomegranate, lemon, papaya, grapes, the cost could go up. For crops such as castor, cotton, fennel and vegetables, the cost would go further up as denser laterals and drippers would be required. Even for low cost micro tube drips, the cost per ha would vary from Rs. 12000 for sapota and mango to Rs.28000 for pomegranate to Rs.40000 for castor.

Keeping in view these perspectives and situations, economics of water-saving technologies can be simulated for four typical situations for alfalfa in Banaskantha district of north Gujarat based on real time data collected from four demo plots in farmers' fields. Alfalfa is an annual crop used as forage grown in north Gujarat region, including Banaskantha district.

The first level of analysis is limited to private cost-benefits (level 1). Yield increase and labour saving are the private gains here. The annual yield benefit was estimated by taking calculated daily yield increase (col. 3-col. 5 in Table 11) and multiplying by 240, which is the approximate number of days for which the fodder field yields in a year. The labour saving benefit was calculated by taking the irrigation equivalent (in daily terms) of total water saved (total volume of water saved/discharge of pump in 8 hours) and multiplying it by the daily wage.

In the second level of analysis, the actual economic cost of using every unit of electricity is considered as a benefit from saving every unit of the energy (level 2). In this case, the energy saving and cost saving depend on two factors: the energy required to pump unit volume of groundwater, and the total volume of water saved. Here, it is assumed that no extra energy would be required for using the inline drip system, which is connected to the existing pumping devise[15]. In the third level of analysis, the unit price of water in the market was treated as economic gain from "actual saving" of every unit of water and was added to the cost of electricity to pump unit volume of water (level 3). This was multiplied by the total volume of water saved to obtain the total economic gain in excess of the gain from yield increase and labour saving. The fourth level of analysis for farmers who are irrigating with purchased water. Here in this case, the unit price of water could be considered as a private gain from saving every unit of water (level 4). In this case, the cost of construction of a storage tank and a 0.5 HP pump are added to the cost of installation of the system. The results are presented in Table 10.

Table 10: Economics of Drip Irrigation in Alfalfa for Four Different Situations

Plot No.	Initial Cost of the System (US $)	Total Water Saving/ Year (M3)	Equivalent Energy Saving/ Year (K.W. hr)	Labour Saving / Year (person days)	Yield Increase From the entire plot (Kg)	Private Benefit/ Cost (Level 1)	Economic Benefit/ Cost Ratio (Level 2)	Economic Benefit/ Cost Ratio (Level 3)	Private Benefit/ Cost Ratio (for water buyers) (Level 4)
1	157.0	479.50	149.00	4.00	448.00	1.09	1.83	2.78	1.39
2	136.0	111.30	92.30	6.00	409.00	1.29	1.48	1.74	0.99
3	201.0	63.60	31.60	4.90	586.00	1.10	1.18	1.28	0.88
4	168.0	468.00	232.80	6.00	414.00	1.05	1.73	2.59	1.33

Source: The authors' own estimates based on primary data

An analysis of economics of some water-saving technologies (pressurized drips, sprinklers and micro tubes) was attempted on the basis of data on crop inputs and outputs, and capital investments collected from

[15]The system being designed and installed for small plots of 500 m2 with an operating pressure requirement of 0.4kg/cm2 for the inline drips, all the farmers who used the system ran them under the residual head.

primary survey of adopters and non-adopters for Kachchh, Bhavnagar, Rajkot and Banaskantha districts. While Kachchh has arid climate, Bhavnagar and Rajkot have semi arid climate. The results are presented in Table 11. The analysis is based on the estimates of incremental returns from drip irrigation over the entire life of the system against the additional capital investment for the system. For calculating the present value of an annuity, a discount rate of 6% was used and the life of the system was considered as 10 years. The incremental returns considered are the average of two consecutive years. This was done to take care of the problems of yield reductions due to crop failure and price fluctuations. While estimating incremental returns, the effect of differential input costs, and differential return were considered. The benefit cost analysis was carried out for three important crops in all the four districts irrigated by micro irrigation systems and are presented in Table 11.

Overall, two major findings emerge from the results of benefit-cost analysis. First: for cash crops and orchard crops, the B/C ratio often become very high but with wide variations across crops. For instance, in case of castor in Banaskantha, the B/C ratio is 5.2, whereas it is only 0.56 for the same crop in Kachchh. Second: for conventional field crops, the B/C ratios are generally low, but with low variation.

Table 11: Private costs and returns from micro irrigation in the selected districts

Sl. No.	Crop	Incremental net income (Rs)	Incremental annual cost of the system (Rs)	B/C Ratio
Rajkot				
1.	Chilly	17518.28	16792.63	1.06
2.	Cotton	20064.84	6266.75	3.30
3.	Groundnut	7574.25	9216.00	1.30
Banaskantha				
1.	Alfalfa	49062.77	9998.76	4.90
2.	Bajra	1787.88	1221.13	1.40
3.	Castor	5373.78	1016.48	5.20
4.	Mustard	6021.25	3970.70	2.00
5.	Wheat	2305.95	2602.72	0.98
Kachchh				
1.	Banana	54297.21	10949.73	6.00
2.	Cotton	17303.65	11158.78	1.70
3.	Lemon	34029.61	15677.26	2.70
4.	Mango	8570.48	8386.90	0.94
5.	Brinjal	42816.90	32608.70	1.30
6.	Castor	18953.74	33840.17	0.56
Bhavnagar				
1.	Groundnut	3509.98	685.47	5.10
2.	Bajra	2155.14	2559.86	0.84
3.	Jowar (Fodder)	38150.91	8861.06	4.30
4.	Cotton	3719.35	2138.46	1.70
5.	Mango	29901.90	1953.13	15.30
6.	Lemon	3933.28	2822.49	1.40

Source: Authors' own estimates based on primary survey

It is noteworthy that the incremental net returns were generally markedly higher for cash crops viz., ground nut, cotton, castor; and fruits viz., mango and banana than for food crops viz., bajra and wheat. This is in conformation with the work of earlier researchers (see Narayanamoorthy, 1997; Sivanappan, 1994; Narayanamoorthy, 2003). The incremental returns from cash crops, particularly fruits, could, however, fluctuate significantly depending on the price and yield fluctuations. At the same time, it is also equally striking to note that the benefit-cost ratios are good for cereals also given the fact that the capital cost of the system is high and the market value of the produce is not high. Perhaps, this could be because farmers who did not use the system faced significant yield losses due to water stress.

4. POTENTIAL FUTURE BENEFITS FROM MICRO-IRRIGATION TECHNOLOGIES

This section is based on inference drawn from section 3 concerning the conditions under which micro irrigation system becomes a good bet technology.

Table 12: Crops conducive to water-saving technologies in India and their Potential Spread

Crop Category	Different crops conducive for WSTs	Type of WSTs that can be used	Regions*
Tree crops and orchards	Mango, Guava, Goose-berry, Pomegranate, Sapote, Orange, Coconut, Banana, Date palm, Grapes, Papaya, Citrus and Kinnow, Drumstick	Drips (for all); and also Sprinklers (Banana, Mango) and plastic mulching in case of extreme water stress	Maharashtra, Andhra Pradesh, Kerala, Karnataka, Tamil Nadu, and Punjab
Row field crops	Potato and Groundnut	Drips; and also mulching (for groundnut and potato)	Gujarat, Maharashtra and Punjab
Plantation Crops	Coconut, Coffee, Tea, Teak	Drips (for coconut and teak); and sprinklers (for tea and coffee)	Kerala and Karnataka (coconut, tea and coffee), Orissa (tea); Tamil Nadu (coconut)
Field Crops	Wheat, Pearl millet, Sorghum, Maize, Alfalfa, Mustard	Overhead sprinklers (wheat, pearl millet, maize and sorghum) and mini and micro sprinklers for alfalfa	Punjab, Haryana, Gujarat, Maharashtra, Rajasthan and Madhya Pradesh, Andhra Pradesh, and Karnataka
Fruit/Vegetables	Tomatoes, Cucumbers, Capsicums, Brinjal, Gourds, Chilly, Cabbage, Cauliflower, Strawberry	Drips, and plastic mulching	Maharashtra, Gujarat, Rajasthan, Andhra Pradesh, Tamil Nadu, Karnataka
Cash crops	Cotton, Fennel, Castor, Sugarcane, Vanilla and Cumin, betel vines	Drips for sugarcane; fogger sprinklers for Vanilla; and micro sprinklers for cumin	Maharashtra, Tamil Nadu and Gujarat (for cotton, sugarcane and ground nut), Gujarat for cumin and fennel, Orissa and central India for betel vines, and Kerala for vanilla

Note: Drips include pressurized drips (integrated drips, emitters, drip tapes); easy drips; micro tube drips; Regional priority only indicates, any of these crop types could be grown there and not all the crops under the category

4.1 Crops Conducive to Micro-irrigation Technologies

A rigorous analysis of published and unpublished literature shows that there are a wide range of crops that are conducive to micro-irrigation technologies from physical feasibility point of view. They could be classified into: 1] tree crops and orchards; 2] row crops; 3] plantation crops; 4] field crops; 5] vegetables; and 6] cash crops. A list of crops which are conducive to different water-saving irrigation technologies are presented in Table 12. However, this does not mean that micro irrigation systems would be economically viable for these crops in the regions mentioned.

4.2 Water-scarce River Basins that can benefit from Micro-irrigation Technologies

Though the economic viability of MI systems for a given crop would depend on a wide range of factors, such as natural environment (soils and climate), production conditions, market conditions, spread of the technology in an area and the type of price considered for economic evaluation (whether, farm gate price or market price) due to paucity of data on the actual conditions for which the evaluation is performed, general conclusions are drawn on the conduciveness of the basins to the technologies based on the available data and the knowledge about the regions' physical and socio-economic conditions and institutional settings.

That said, there are many basins that can benefit from MI devices. But, the extent to which it can contribute to overall improvement in basin water productivity would depend on: 1] the total area under crops that are conducive to micro irrigation devices in the basin; 2] the types of sources of irrigation of those crops, i.e., whether lift irrigated or gravity irrigated; 3] the climatic conditions in the basin; and, 4] the geo-hydrological conditions.

We have seen that crops that are served by gravity irrigation are least likely to be covered under MI systems due to physical, socio-economic and institutional constraints. Hence, large areas of Haryana, Uttar Pradesh, and Punjab offer no potential for scaling up of micro irrigation systems as mostly they are covered under canal systems. Over and above, paddy, one of the major crops grown in these areas, is also not conducive to water-saving irrigation devices. Though sprinklers can be used for wheat, the water-saving and yield impacts are not likely to be significant enough to motivate farmers to go for it. Nearly 55% of the groundwater in Haryana is saline and alkaline, and the problems are more severe for deeper aquifers in the region (Kumar, Dhindwal and Malik, 2003:pp9). The use of groundwater for irrigation itself is marginal, making micro irrigation system adoption difficult. In Bihar, leaving aside the problem of low appropriateness of the prevailing cropping system (comprising wheat and paddy), power crisis would be a stumbling block in adopting sprinklers which are energy-intensive.

As regards climate, most of Ganga-Brahmaputra-Megha basin covering most parts of Uttar Pradesh, Bihar, and north east has sub-humid and cold climate, and the extent of water-saving possible through MI system adoption could be quite insignificant.

If we consider physical availability of water, physical conditions of water supply and land use, cropping systems, groundwater table conditions, the basins where MI system adoption could take off and where it would result in enhancement in basin level water productivity are: west flowing rivers north of Tapi (river basins of Saurashtra, Kachchh and Luni in Rajasthan); Banas, Sabarmati, south-western parts of Punjab and Haryana in Indus; Cauvery basin; Krishna basin; Pennar basin; Vaghai basin; Narmada; downstream areas of Tapi; Mahanadi and Godavari.

The enhancement in water productivity would come from two phenomena - 1. Reduction in the amount of water depleted with no effect on crop consumptive use. 2. Raising the yield of all the crops that are grown in these basins. Nevertheless, within these basins, there are areas where the groundwater table is very shallow, and climate is sub-humid. They include: south and central Gujarat, which fall in the downstream of Tapi and Narmada.

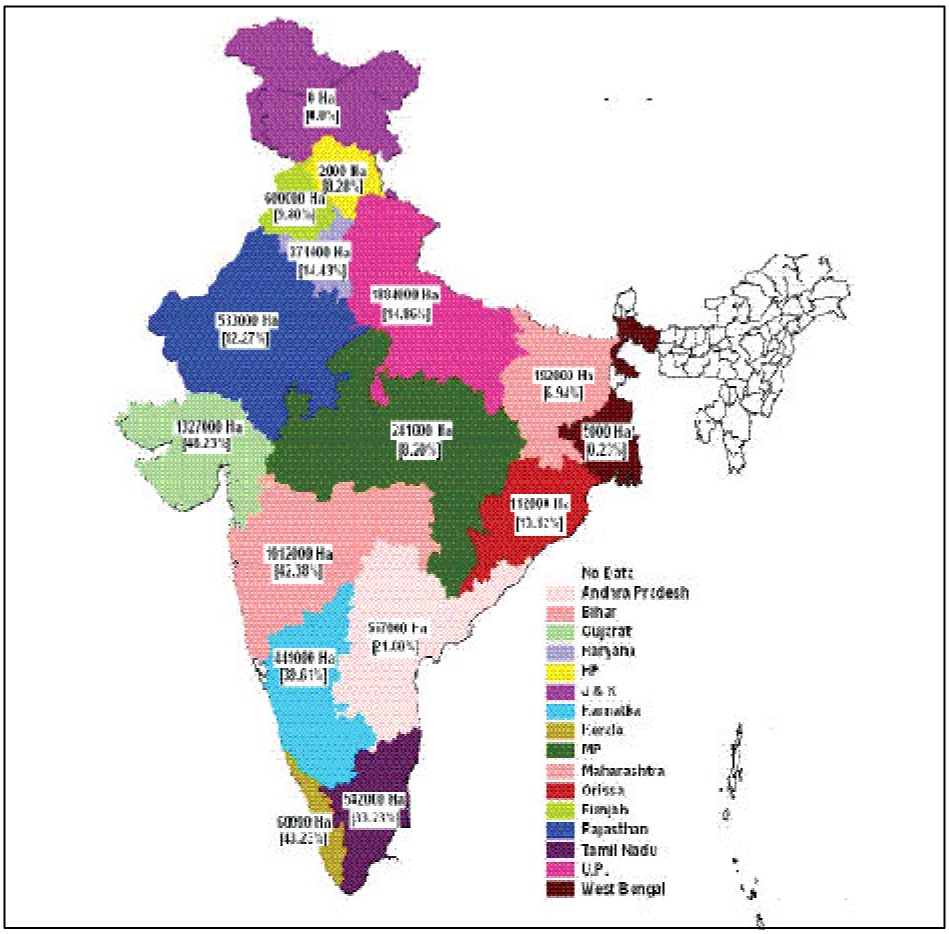
The western Ghat areas in Kerala, Karnataka, Maharashtra and Goa provide favourable environment for adoption of micro-irrigation devices due to the presence of tree and fruit crops and plantation crops such as coconut, arecanut, coffee, tea, mango and banana. The semi arid, hard rock areas of Tamil Nadu, Karnataka, Andhra Pradesh, Maharashtra and most parts of Gujarat, provide favourable environment for adoption of MI systems owing to limited groundwater potential; the dominance of well irrigation; and dominance of tree crops, fruit crops, cash crops, row crops and vegetables. At the same time, there would be real saving in water due to declining groundwater table in these regions.

The available data on adoption of micro irrigation systems in different states of India during the past four years is a testimony to what has been discussed in the preceding paragraphs. The highest area under drip irrigation is in Maharashtra (22358 ha). This is followed by Andhra Pradesh (17556 ha), Karnataka (16731 ha) and Gujarat and Rajasthan. But, at the aggregate level, micro irrigation accounts for nearly 1.6% of India's total irrigated area, against 21% in the United States, and 30% (8% under drips and 22% under sprinklers) in Australia.

4.3 Area that can be brought under MI Technologies in Major Indian States

The map shows the area under different crops that are conducive to MI devices in different states of India. The empirical basis for estimating this: 1] the gross irrigated area under such crops; and 2] the percentage of net irrigated area under well irrigation in the respective states. Such approach has the inbuilt assumption that percentage area under well irrigation is uniform across crops. This may not be true. In fact, it has been found that in surface irrigated areas, farmers normally take water-intensive, but less water-sensitive crops. It considered only 16 major states, and had excluded the minor states (13 nos.) and Union Territories. Further, it has excluded area under crops viz., wheat, mustard, rapeseed, pearl millet and sorghum which can be irrigated using sprinklers, but with poor results in terms of water-saving, and had included only those which are amenable to drips and plastic mulching.

It shows that Uttar Pradesh has largest area (1.884 million ha) under crops amenable to WSTs. It is followed by Gujarat with 1.327 million ha, and Maharashtra with 1.012 million ha.



4.4 Basins and Cropped Area Conducive to Adoption of Micro-irrigation Technologies

In order to estimate the figures of "total irrigated cropped area that would benefit from MI systems", we have superimposed the cropped area that are conducive to MI systems, and the basins where MI adoption would lead to real water saving, and water productivity improvements.

The earlier analysis has shown that peninsular and western India had substantial area under crops that are conducive to MI technologies. It has also shown that central and north India have very little area under such crops. Uttar Pradesh is an exception, which accounts for nearly 25% of the area that is conducive to MI systems. The basins in peninsular, western and central India have natural environments (soil, geo-hydrology, climate), wherein MI adoption can actually result in real water saving and basin level water productivity improvement. Western part of Mahanadi is also conducive to MI systems. But, in Ganga-Brahmaputra basin, in which UP falls, adoption is going to be poor due to poor rural electrification; relative water abundance; shallow groundwater in most areas; and very low size of operational holdings of farmers. Even if this region adopts MI systems on a large-scale, it may not result in reduction in depleted water, but a little difference in crop yields, with the resultant meager increase in water productivity at the basin level. Hence, Ganga-Brahmaputra-Meghna) have to be excluded from our analysis.

The cropped areas that will benefit from MI system would hence be from: 1] basins of all east-flowing rivers of peninsular India; 2] basins of west-flowing rivers north of Tapi in Gujarat and Rajasthan; Mahanadi; some parts of Indus basin covering south-western Punjab; and west flowing rivers of South India. The total would be 5.844 m ha (79.30-20.86) of cropped area. This is the absolute potential, and the real adoption would depend on several socio-economic and institutional factors.

Now, let us look at the area estimates provided by Narayanamoorthy (2004b), and the task force on MI in India. Narayanamoorthy (2004b) provided an estimate of 21.27 m. ha as the net area under all irrigated crops that can be brought under drip systems in India, with an upper figure of 51.42 m. ha including area under those crops, which are currently rain-fed. But this analysis did not consider the several physical and socio-economic factors that would ultimate determine the viability of drips for these crops. The task force on MI had estimated a figure of 69 m. ha as the area suitable for MI systems in India. It is quite clear from such a high figure that the task force estimates had included all regions and area irrigated by different types of irrigation systems, therefore not considered the physical (technical, and hydro-meteorological), and socio-economic constraints in the adoption of MI systems.

4.5 Quantification of Potential Future Impact of MI Systems on Water Requirements

In order to analyze the impact of MI devices on aggregate water requirement for crop production in India, we started with the data provided in Table 2 in which data on water use efficiency[16] impact of drip irrigation for various crops are presented. A total of six crops, for which country-level data on irrigated crop area are available, were considered for estimating the future water-saving benefits. Then the data on aggregate output from these crops are obtained. Assuming that the same output for the respective crops is to be maintained in future, the future water requirement for growing the crops could be estimated by dividing the improved water use efficiency figures by the crop output.

The reduction in water requirement for crop $_i$ = Present Output of Crop $_i$ [1/Current Water Productivity -1/Improved Water Productivity]

The procedure can be repeated for all crops.

* States where MI systems are likely to be adopted. This is obtained by multiplying the average crop yield under conventional irrigation (as provided in Table 4) with the sum of the estimated area under that crop in each state. The water productivity figures are estimated from the yield and water consumption figures provided for the respective crops in Table 4 of this report.

[16] We treat them as water productivity values as the modified values of WUE capture the net effect of improved water application and improved agronomic practices.

Table 13: Aggregate Reduction in Water Requirement for Crop Production Possible with Drip Irrigation Systems

Sr. No	Name of Crop	Current Yield (ton/ha)	Expected Yield Coming from the Potential States* (million ton)	Water Productivity (Kg./m^3)	Improved Water Productivity (Kg./m^3)	Reduction in Crop Water Requirement (BCM)
1	Sugarcane	128.0	170.0	5.950	18.09	31.00
2	Cotton	2.600	4.391	0.303	1.080	10.42
3	Groundnut	1.710	2.840	0.340	0.950	1.453
4	Potato	23.57	34.47	11.79	17.21	0.127
5	Castor	1.260	1.350	0.340	0.670	0.497
6	Onion	9.300	12.20	1.544	2.700	0.963
7	Total					44.46

While estimating the crop area that are likely to be brought under drips, the area under the respective crops in water-abundant states viz., UP, Bihar, West Bengal, Haryana and north eastern states were subtracted. The aggregate reduction in crop water requirement due to the adoption of drip systems was estimated to be 44.46 BCM. It can also be seen that highest water-saving could come from the use of drips in sugarcane, followed by cotton. This is the maximum area that can be covered under the crops listed in well-irrigated areas, provided all the constraints facing adoption are overcome through appropriate institutional and policy environments. In the subsequent section, we would discuss what these policies are.

5. INSTITUTIONAL AND POLICY ALTERNATIVES FOR SPREADING MICRO-IRRIGATION TECHNOLOGIES

The most ideal policy environment for promotion of MI technologies in well irrigated areas is pro-rata pricing of electricity. While this creates direct incentive for efficient water use (Kumar, 2005), to what extent the MI technologies would reduce energy use depends on the crop type and the type of technology (pressurized system or gravity drip system) used for the crop. Not all MI technologies are energy efficient. Hence, bringing non-conventional (non-pressurized) drip systems under subsidies is very important, once pro-rata pricing of electricity is introduced. It would also force farmers in areas irrigated by diesel engines to adopt such MI systems as it could save diesel and reduce input costs.

While in the long run, total metering and consumption-based pricing would be the most desired (Kumar, 2007), the governments can start with metering of agricultural consumption. Cash incentives or heavy subsidy for MI devices could be provided to farmers who are willing, provided they minimize electricity consumption. This cash incentive could be inversely proportional to the total energy use and directly proportional to the percentage area under MI system. This would create incentives for farmers to maximize the coverage of MI systems in their irrigated crops, particularly less energy intensive crops; and limit the total irrigated area.

Improving power supply, both quality and duration, is extremely important for boosting adoption of pressurized MI devices in many areas. Such areas include alluvial north Gujarat and south-western Punjab. One can argue that with improved power supply, groundwater use could go up. However, in reality, with improved hours of power supply, the quality of irrigation would go up, enabling farmers to realize the full potential of MI systems. The actual impact of improved power supply regime on sustainability would depend on the type of crops farmers grow with MI systems, and the availability of extra land for area expansion.[17]

[17] In areas where the entire cultivable land is under irrigation, adoption of MI devices would result in reduction in groundwater use at the farm level. Subsidies are required here to promote MI adoption as it would lead to social benefits from reduced stress on groundwater

All these policy measures would help address the issues in well-irrigated areas. Still, a large chunk of the irrigated area (23.606 million ha in 1999-00 in India, source: Ministry of Agriculture and Cooperation, GoI), which is from surface sources, would be left untouched. In addition to amendments in administration of subsidies and improvements in extension activities, the way to bring these areas under MI systems is to either change the delivery practices or to increase the economic incentives.

The water delivery systems need to be designed such that farmers can directly connect the source to their distribution system. The irrigation schedules need to be reworked so that the duration between two turns becomes much shorter than the present duration of 2-3 weeks. In the ideal situation, the supply should be perennial. This can happen in the most advanced stage of irrigation systems design and would take time. Moreover, it can be thought about only in case of new schemes. One of the reasons why the farmers in Israel adopt micro irrigation systems at such a large-scale (with 95% of the irrigated crops are under drip systems) is that the surface water is delivered in their fields under pressure through pipes.

Economic incentives for MI adoption in canal commands can be improved by increasing the price of irrigation water. High prices for irrigation water increase cost and result in applied water saving. Alternatively, the cost of building intermediate storage systems can be reduced through proper design of subsidies. In command area of Indira Gandhi Canal Project, most of the farmers are using intermediary storage tanks locally called "*Diggi*". The farmers are using electric pump for lifting this water and irrigating crops whenever they required. After seeing the benefits of such interventions on reducing the pressure on the resource, government has started providing subsidy for construction of "*Diggi*". Many farmers are using sprinklers to irrigate their crops from the tank water.

Apart from saving the cost of water, the differential economic returns farmers get under lift irrigation over canal irrigation (IRMA/UNICEF, 2001; Kumar and Singh, 2001) and the differential return in drip irrigated crops would be the strongest incentive for farmers to go for intermediate storage systems. The justification for subsidizing the systems is that the private benefit-costs ratio would not be very attractive with very high capital cost of the system and the additional infrastructure, whereas the social benefits accrued from saving the scarce water resources would be high when compared against the social costs. The differential returns could be due to the better control over water delivery possible with lift (IRMA/UNICEF, 2001) or due to the increased ability to grow cash crops such as cotton, banana, and fruits and vegetables in the command areas. With this, the actual area that could be brought under MI systems would be larger than the potential area estimates we have provided.

Improving the administration of subsidies is necessary to increase welfare impacts. The farmers should be made to pay the full cost of the system initially, and subsidies be paid in installments based on periodic review of system performance. As manufacturers have to sell the system at the market price, it would compel them to improve the competitiveness of their products, and also provide good technical input services. Rural credit institutions can advance loans to farmers for purchase of MI systems to maximize coverage to include small and marginal farmers. In Gujarat, a new model for promoting MI devices is being implemented by the state government through a state-owned company called Gujarat Green Revolution Company (GGRC). Under this model, the subsidy is paid by GGRC to the farmer in installments, and the results are very encouraging. Not only is the adoption of MI devices fast, but significant percentage of the adopters belongs to small holder category, having less than 2.0 ha of land. They use it for cash crops viz., cotton, ground nut, potato and vegetables. Within a year after the creation of GGRC, a total of 30,000 ha of crop land had already been brought under drips in the state.

On the other hand, there is a need for creating a separate agency for promoting MI in each state to increase the speed of processing of application from farmers. The agency can work in tandem with the manufacturers and farmers to enable timely technical inputs to the farmers. In areas where agricultural processing units are concentrated, provision of all critical inputs including subsidies would not be a problem, as they could come from these processing units. The example is that of sugarcane and grape grower cooperatives of Maharashtra. However, in areas where demand for drip irrigation is scattered vis-à-vis crops and geographical spread, this would be an issue. A new agency should facilitate survey of farmers' fields by the manufacturer, and get the designs and estimates prepared along with the most desirable cropping system. This would also help farmers procure the system well in advance of the crop season to make full benefit of it.

6. MAJOR FINDINGS

1. The extent of adoption of MI devices in India today is just 1.6% of the total irrigated area, due to the lack of favourable, physical, socio-economic, institutional and policy environments. Adoption is also heavily skewed vis-à-vis geographical spread and crops.
2. The available literature shows that drip irrigation leads to substantial saving in applied water over conventional method of irrigation, yield improvements, and improvements in water use efficiency. The extent of field level water saving is the highest for orchards. The available data are from experimental farms; and social research. Both have limitations. In the first case, issue is of replicability and in the second case, the reliability and adequacy of data.
3. There are methodological issues involved in the estimation of water-saving and water productivity impacts of MI systems. The available estimates are based on the assumption that all the water applied to the crop is depleted. But, in view of the fact that MI devices are mostly adopted in semi arid and arid regions with deep and falling water table conditions, such methodological compromises can also yield reliable results.
4. Analysis of the potential contribution of MI systems in India in reducing the aggregate demand for water in crop production involves three complex considerations: 1] the extent of coverage of MI systems that can be achieved at the national level; 2] the extent of real water saving possible with MI system adoption at the field level; and 3] what farmers do with the water saved through MI systems, and the changes in the cropping systems associated with adoption.
5. Some of the factors that limit the expansion of MI technologies in India are: 1] lack of independent source of water and pressurizing device for many farmers; 2] poor quality of groundwater in many semi arid and arid regions; 3] mismatch between water delivery schedules in surface irrigation systems, and irrigation schedules required in MI systems; 4] cropping systems that dominate field crops in semi arid regions; 5] dominance of small and marginal farmers, and small plot sizes; 6] low opportunity costs of pumping groundwater due to lack of well-defined water rights; 7] negative technical externalities in groundwater use; viii] poor extension services; and 8] poor administration of subsidies.
6. The field level water saving due to MI systems depends on: a] the geo-hydrological environment; b] crop type; c] agro-climate; d] type of MI technology. Water saving impacts would be high for drip systems, particularly under arid to semi arid climate, for widely spaced row crops, when groundwater table is deep. While MI system would result in field-level water saving in various degrees, depending on the situation, its impact on aggregate water use would depend on the groundwater availability vis-à-vis power supply situation, the crops farmers choose with MI, and the extra land available for cultivation. In groundwater scarce areas, MI adoption would result in area expansion, with no likely reduction in aggregate groundwater draft.
7. Available studies on the costs and benefits of MI systems suffer from many inadequacies. First of all, they do not capture the physical settings, the socio-economic conditions and institutional and policy environments that affect the actual private, economic and social benefits from MI adoption. Secondly, some of the analyses are based on direct costs and returns and not incremental costs and benefits associated with system use.
8. A comprehensive analysis of economics of different WSTs for different crops across Gujarat shows that B/C ratios are highly influenced by crop choices and largely limited to high value crops (fruits and some vegetables), which have further capital investment requirements apart from the irrigation system.
9. The river basins that are likely to benefit by and are also conducive to MI systems are: western part of Indus in Punjab and Haryana; west-flowing rivers north of Tapi; east-flowing rivers south of Tapi; west-flowing rivers south of Tapi in the Western Ghats; Sabarmati; and Mahanadi. In these basins, extensive adoption of efficient irrigation technologies would result in overall enhancement in basin-level crop water productivity. The total well-irrigated area that can be potentially brought under MI systems from 16 major states of India is estimated to be 5.6 million ha.

10. The total potential reduction in crop water requirement with the full adoption of drip systems in six selected crops is estimated to be 44.46 BCM. It can also be seen that highest reduction in water requirement could come from the use of drips in sugarcane, followed by cotton. Both the estimates are much lower than the estimates provided by Narayanamoorthy (2004b) and that by the Task Force on Micro Irrigation in India.

7. CONCLUSIONS

Adoption of MI systems is likely to pick up fast in arid and semi arid, well-irrigated areas, where farmers have independent irrigation sources, and where groundwater is scarce. Further, high average land holdings, large size of individual plots, and a cropping system dominated by widely spaced row crops, which are also high-valued, would provide the ideal environment for the same. The extent of real water-saving and water productivity improvements at the field level through adoption of MI systems would be high for widely spaced row crops, in arid and semi arid conditions, when the groundwater table is deep or aquifer is saline. In hard rock areas with poor groundwater potential, MI adoption would result in improved efficiency of water use, but would not reduce the total groundwater draft.

In semi arid and arid areas, which face severe groundwater scarcity, the economics of MI systems would be sound for high-valued cash crops. In areas where electricity charges are not based on power consumption, and opportunity cost of using water is zero, the saving in energy and water achieved through MI system do not get translated into economic benefits. Hence, economics of MI system will not be sound in such areas. But, the evaluation studies are skewed towards drip systems, and do not capture the effect of changing physical, socio-economic and institutional settings on the economic dynamic.

The future potential of MI systems in improving basin level water productivity is primarily constrained by the physical characteristics of basins and the opportunities they provide for real water-saving at the field level, and area under crops that are conducive to MI systems in those basins. Preliminary analysis shows very modest potential of MI systems to the tune of 5.69 m ha, with an aggregate impact on crop water requirement to the tune of 43.35 BCM possible with drip adoption for six selected crops. Creating appropriate institutions for extension, designing water and electricity pricing policies apart from building proper irrigation and power supply infrastructure would play a crucial role in facilitating large-scale adoption of different MI systems. The subsidies for MI promotion should be targeted at regions and technologies, where MI adoption results in real water and energy saving at the aggregate level.

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