Water Saving and Yield Enhancing Micro-irrigation Technologies: How Far Can They Contribute to Water Productivity in Indian Agriculture?

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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 with the available future supplies, thereby reducing the extent of water stress that the country is likely to face (Kumar 2003a; Kumar 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.

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 system to river basin. 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 the 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 the 'wet water' saving in irrigated production at the field level can come only from reduction in the 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. These are due to the complex considerations, including agronomic, hydrologic, geo-hydrological and geo-chemical, in 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 2003). Efficient irrigation technologies help establish greater control over water delivery (water control) to the crop roots, reduce the non-beneficial evaporation from field and non-recoverable percolation,[1] and return flows into 'sinks' and often increases the beneficial ET, though the first component could be very low for field crops. Water productivity improves with the reduction in depleted fraction and yield enhancement. Since at the theoretical level, water productivity improvements in irrigated agriculture can result in saving water used for crop production, any technological interventions which improve the 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. But, only micro- irrigation technologies, which are based on plastics, are dealt with in this paper. India stands 27th in terms of the scale of the adoption of water-saving and yield enhancing micro-irrigation devices (source: www.oznet.ksu.edu/sdi/News/Whatisnew.htm). There are several constraints to the adoption of MI devices. These are physical, socioeconomic, financial, institutional—pricing, subsidies, extension service—and policy-related in nature (Narayanamoorthy 1997; Sivanappan 1994; Kumar 2003a). Nevertheless, a systematic attempt to find out the conditions under which MI systems become a best bet technology, and assess the magnitude of the reduction in water requirement possible through them is hardly ever made. Such efforts are crucial from the point of view of assessing our ability to address future water scarcity problems at the regional and national level.

The ultimate objective of this research is to find out under what conditions micro-irrigation system offers the best bet. It aims at determining the potential benefits from the use of MI systems. This includes assessing a) the conditions that are suitable or unsuitable for MI systems; b) the field level and aggregate level impacts of the systems on water use; and c) the yield and economic benefits due to the 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 possible with that.

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[1] Allen et al. 1998 for definitions of non-beneficial evaporation and non-recoverable deep percolation.

Contribution of Micro-irrigation Technologies in Indian Agriculture

Present Spread of Micro-irrigation Technologies in Indian Agriculture

There were no systematic attempts in the past to assess the spread for water-saving irrigation technologies in India. The most recent data shows that nearly 1.3 m ha of irrigated land is under drip irrigation (Narayanamoorthy 2004b).

They cited high initial cost (including mis-targetted subsidies), clogging of drippers and cracking of pipes, lack of adequate technical inputs, damage done by rodents; high cost of spare components; and insufficient extension education effort as the major problems causal of 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). Difficulty in inter-cultivation was found as another reason for non-adoption by Shiyani et al. 1999, whereas Palanichamy et al. 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 by-passed 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 4 years, peninsular India had recorded the highest growth in the adoption of drip systems. Maharashtra ranks first (22,358 ha), followed by Andhra Pradesh (17,556 ha) and Karnataka (16,731 ha). The major crops for which drip systems are currently adopted are cotton, sugarcane; banana, orange, grapes, pomegranate, lemon, citrus, mangoes, flowers, and coconut.

Though exact state-wise data on the spread of sprinkler systems are not available, it has been found that sprinkler systems are in vogue in regions where conditions are unfavorable for the traditional method of irrigation, such as loose sandy soils and highly undulating fields. These are well-irrigated areas. Farmers in other well-irrigated areas have also procured the system under the government subsidy program, but were found to be using the HDPE pipes for water conveyance in the field except during droughts when they are used 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 parts 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 do sowing of these crops, or when there is a long dry spell during the monsoon season. Sprinklers for groundnut are common in Saurashtra in Gujarat; they are also common for mustard in Khargaon District of Madhya Pradesh and the 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.

Potential Contribution of Micro-irrigation Technologies in India

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 such 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 and 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, socioeconomic and institutional factors that induce severe constraints to the adoption of these technologies. Second, they do not distinguish between saving in applied water and real water saving, while the latter possible through MI adoption could be much lower than the former. 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 the introduction of MI systems, farmers might change the very cropping system itself, including expansion in the 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.

A) Physical Constraints and Opportunities for Adoption of MI Systems

Determining the potential coverage that can be achieved in MI system adoption requires a systematic identification of the conditions that are favorable or unfavorable for adoption and a geographical assessment of areas where such conditions exist. Such conditions can be physical, socioeconomic or institutional. These physical, socioeconomic 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 the 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 evapotranspiration from crop land; and ii) maintaining the area under irrigation. The second issue is not 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). However, their adoption is very low in India. While, there are several constraints at the field level, which limit the adoption of this technology by the farmer, some of the very critical ones that are physical in nature are analyzed here.

First of all, MI systems need a 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

(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 to be followed when MI systems are used. 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 2 days with lower flow rates equal to evapotranspiration. 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 content in the canal water supplies. Second, there is a need for pumps for lifting water from the storage facilities and running the MI systems. These two investments would reduce the economic viability of MI.

Therefore, in the current situation the 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 overdraft is not a concern like in Bihar and western Orissa, and where economic access to water is a problem. It is difficult to imagine that these farmers would adopt any water saving irrigation devices.

MI systems are also energy-intensive systems and, therefore, need pressuring devices to run. Therefore, 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 do not own wells, and have to depend on water purchase. They get water through underground pipelines at almost negligible water pressure (head). These farmers constitute a major chunk of the irrigators in the region. 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 tubewell, 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. The farmers who are either water buyers or share wells can store the water in small tanks and 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 2,000 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 irrigating *kinnow* (a kind of citrus) orchards. These farmers can also use this water for drip irrigation to prevent problems of clogging.

In addition to the areas irrigated by groundwater, there are hilly areas of the western and eastern Ghat regions, north-western Himalayas (Himachal Pradesh, J & K 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 virtue of the elevation difference, which is in the order of 30-40 meters. Such systems are used to irrigate banana, vegetables and other cash crops such as vanilla. With the creation of an intermediate storage, drips could be run for irrigating crops such as coconut, arecanut and other fruit crops during the months of February to June.

The geological setting has a strong influence on MI adoption in well-irrigated areas. In hard rock areas, farmers will have a 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 the shortage of water. In most of these areas, farmers will have to discontinue pumping after 2-3 hours for the wells to recuperate. When pressurized irrigation systems are used, the rate at which water is pumped decreases giving enough opportunity time for wells to recuperate. Since, the 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.

B) Socioeconomic and Institutional Constraints for MI Adoption

Another major constraint on the adoption of 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). This is because the additional investment for drips has to be offset mainly by the better yield, and the returns farmers get as the saving in input costs are not very significant. But, the percentage area under horticultural crops is very low in these regions, except Maharashtra. Though the low-cost drip irrigation systems appear to be a solution, they have low physical 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 in the economic viability front. The low-cost systems can be used for some of the row crops such as castor, cotton and fennel, which are very common. 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 uneven (unfavorable) field conditions, designing and installing drippers becomes extremely difficult. Therefore, for the adoption of these water saving technologies, the farmers’ agricultural practices need major changes.

Further, there are crops such as paddy for which 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 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 any 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 socioeconomic viability of crop shifts increases with the size of the operational holding of farmers. Given the fact that small and marginal farmers account for a large percentage of the operational holders in India, the adoptability of horticultural crops by farmers in these regions cannot be expected to be high. This is because these crops need at least 3-4 years to start yielding returns, (except for pomegranate and papaya). It will be extremely difficult for these farmers to block their parcel of land for investments that do not give any returns in the immediate future, say after a season or so. Market is another constraint. Large-scale shift to fruit crops can lead to sharp decline in the market prices of these fruits. Labor absorption is another major issue when traditional crops such as paddy, which are labor-intensive, get replaced by orchards. Orchards require less labor, 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 and overhead tanks. Also, the additional energy required for running the system will decrease with every additional sprinkler, the reason being that only the pressure loss increases with the increase in the number of sprinklers/drippers (Kumar 2003a). However, organizations like International Development Enterprises (IDE) have developed and promoted MI systems for very smallholder farmers/ plots, which use small storage cisterns for providing the required pressure.

Poor rural infrastructure, mainly in respect of power connections to agro-wells and the quality of power supply, is another major constraint on the adoption of MI systems. Difficulty in obtaining power connections for farm wells, and the poor quality of power supply force farmers to use diesel pump sets for irrigating their crops. The use of diesel pumps 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 on higher capacity pump sets as well as recurring expenses for buying diesel. These factors act as deterrents to adopting MI systems.

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

Unscientific water delivery schedules followed in surface irrigation systems, and power supply restrictions on the farm sector also induce constraints on MI adoption. It is common in surface irrigation systems that while plenty of water is released for the crops during a 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 standard delivery schedules and poor control over volumetric supplies force farmers to adopt crops that are less sensitive to water stress such as paddy and sugarcane and also resort to flood irrigation. Regulated power supply in agriculture is also reducing the economic incentive for the adoption of MI systems that are energy-intensive.

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 demonstrations 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 the 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 interest of promoting MI systems. Since in many states, the governments continue to pay the subsidy directly to the manufacturers, many farmers purchase MI systems just to avail themselves of the subsidy benefits, and do not maintain them. The suppliers do not to offer any after-sales services to the farmers and hence are not interested in ensuring quality control. The systems being supplied are often of substandard quality. Over and above, as the amount of funds available for subsidies is limited, the smartest of the farmers take the benefit. On the other hand, the government officials, who come and inspect the systems installed, only check the amount of materials supplied, and certify them for the release of the subsidy 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 the 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. Though it is the opportunity cost of using water, which influences farmers' decision-making framework, such opportunity costs are not felt clearly. This is in spite of the prevalence of water markets 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. In such cases, the direct additional financial returns the 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 reason is that the gain through the economic efficiency of water use for the irrigated crops grown in the area even with current inefficient practices is much higher than the price at which water is traded (Kumar and Singh 2001).

Presence of negative externalities in groundwater pumping poses an important constraint for those who like to adopt MI systems. Well interference is very common not only in hard rock areas, but also in shallow alluvial areas. Under such conditions, pumping by one farmer will affect 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 him/her. The efforts to save water from the system by an individual farmer might mean increased availability of groundwater for pumping by his/her neighboring farmers. Hence, 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 for groundwater.

C) 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 the improvements in water use efficiency. All the available data on the efficiency impact of micro-irrigation systems are on application efficiency. The classical definition of irrigation efficiency is the ratio of the amount of water consumed by the crop to the amount of water applied. Sivanappan 1994 provides the data on application efficiencies at various stages such as conveyance efficiency, field application efficiency and soil moisture evaporation. 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 if the irrigated soils have salts for the purpose of leaching; and 2) the actual field performance of the irrigation systems is not as good as that shown in experiments and demonstrations.

But 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 unconsumed water is not lost in natural sinks like saline aquifers or swamps (Allen et al. 1998). This means, the application of the concept of irrigation efficiencies is no longer useful in analyzing the performance of irrigation systems, with a greater understanding of agro-hydrology and appreciation of deep percolation from irrigated fields[2] 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 the groundwater table and the nature of the aquifer, whether freshwater or saline; 2) the type of crops; and 3) the agro-climate.

In regions where the water table is deep and showing declining trends, MI adoption can lead to real water saving at the field level. The reason is deep percolation that occurs under the traditional method of irrigation, does not reach the groundwater table. This can be explained in the following way. The reason is that 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 2-3 meters in semi-arid and arid regions (Todd 2003). 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.

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[2] 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.

Nevertheless, in areas where groundwater levels are still within 20 meters 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 the areas having high water table conditions 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 the canopy cover is small.

The 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. 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. Sivanappan 1994 does not provide figures of ‘real water saving’. The extent of this would be determined by the climate (arid, semi-arid or sub-humid or humid), depth to the, groundwater table and groundwater quality, and the amount of water available for deep percolation.

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 data are on experimental farms, for limited number of crops and system types and for a few locations. Data on water-saving, yield rise and water use efficiency improvements with drip irrigation over flood irrigation in several crops, which were compiled from experimental data from different research stations across India (INCID 1994; NCPA 1990) as cited in Narayanamoorthy 2004b: shows that the reduction in water consumption varies from a mere 12 % for ash gourd and bottle gourd to 81 % for lemon.

Some of the figures on water saving provided by INCID and NCPA 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 favor of DMI. However, to obtain high efficiencies, surface methods (furrow, border, and basin) are generally demanding of operating skills and require 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 in 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)[3], and therefore in what environments the comparisons are made is also important. But, it is a truism that 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 in large basins 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. The other methods are small border irrigation, trench irrigation and furrow irrigation, and are generally used by well irrigators.

Crops such as cotton, potato and groundnut are irrigated in furrow as well as small borders. Orchards are irrigated using trench irrigation. On-farm efficiencies are much higher under furrow, trench and small border irrigation as compared with 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 conditions of experimental farms in farmers' fields. For instance, in drip irrigation, the best results are obtained when water is applied daily. But, in actual field conditions, farmers may not be able to apply water daily due to irregular power supply and many other field constraints.

The rest of the data on field level water savings and yield improvements through MI systems are from socioeconomic studies based on respondent surveys involving adopters and non-adopters. The data on water saving are arrived at using figures of the total applied water. The available data from the experimental farms do not enable the 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, one unknown parameter is deep percolation.

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 (based on Ahmed et al. 2004), especially for well irrigation, as the dosage per watering is generally low; 3) the 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 the fallow period (based on Todd 2003). Hence, applied water saving which the available literature refer to can be treated as real water saving.

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[3] 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 (Carteret al. 1999).

But, these studies are not complete in themselves, as they cover a few crops, and a few MI devices. Also, these studies have serious 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.

Field experiments 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 covered the crops 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 for groundnut; and inline drippers and micro-tubes in potato.

The treatments used for alfalfa are different spacing of drippers without changing the water delivery through drippers (30 cm*40 cm in F1 to 50 cm*40 cm in F4); maintaining the same spacing of drippers (30 cm*30 cm) 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; and 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 show that the yield is the 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 35 cm*40 cm (10.71 kg/m^2). But, water productivity was the highest (7.8 kg/m^3 of water) for the plot which recorded the second highest yield (F_2). Therefore, the highest yield corresponds to a depth of application of 1.6 m, while the highest water productivity corresponds to a depth of 1.37 m. With flood irrigation, the yield values were the 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, I_1 is a case of over-irrigation with very heavy doses of irrigation (139 mm) and can be discarded. The figures are relevant in the sense that even 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 three 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 to 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 regards 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 very 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 30 cm*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.

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. The highest yield was obtained under the second highest level of water application (4.33m over the full crop year). The 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 the highest level of irrigation (6.0 m).

Experiments were 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 the 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 the 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 the water application rate was the 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 the highest for C_1, followed by C_4. The water productivity was the highest for C_1, and the second highest for C_2. The difference in water productivity was in the order of 100 % between the first and the last treatment.

Experiments conducted on groundwater with inline drip systems and micro-tube drips showed the highest level of reduction in applied water use in the 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. The micro-tube irrigated plot though gave same yield as that of furrow irrigated plot, the applied water was less with micro-tube. The study shows that the inline drippers are physically more efficient than furrow method and inline drip irrigation.

Another interesting experiment was done with different types of MI devices to understand the physical productivity of 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 having perforations instead of drippers to emit water); micro-tube drips; micro-sprinklers; and mini-sprinklers. The results showed that the yield and physical productivity of water is the highest for fields 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 could 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 the 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.

D) 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 levels due to the widespread adoption of MI systems. This concerns: 1) whether there are real water savings 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 what it makes on water use per unit area of land. While several others believe that with a reduction in the water applied per unit area of land, the farmers would divert the saved water for expanding the area under irrigation, subject to favorable conditions regarding water and equipment availability, and power supplies for pumping water (Kumar 2003a),.[4] and therefore the net effect of the adoption of micro-irrigation systems such as drips and sprinklers on water use could be nil or insignificant at the system level. At the same time, there are others who believe that with the 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 the area under irrigation would increase under WSTs.

These arguments have, however, missed certain critical variables that influence farmers' decision making with regard to the 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 the amount of land and finances available for intensifying cultivation. The most important of these factors is the overall availability of groundwater in an area; and the power supply situation vis-à-vis water availability in the wells.

If power supply restrictions limit pumping of groundwater by farmers, then it is very unlikely that as a result of the adoption of conventional WSTs, farmers would expand the area under irrigation. Let us see how this happens. 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 on 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 the increase in pressure developed in the system. 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. Such outcomes are expected in the alluvial areas of North Gujarat and

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[4] 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 2003a).

Punjab. In this area, even in situations where extra land is available, 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. Central Punjab is an example. But, farmers 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 a 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, it is very likely that with the adoption of micro-irrigation systems, the farmers would expand the area under irrigation. This is the situation in most of the hard rock areas of peninsular India, central India and Saurashtra. Due to limited groundwater potential and overexploitation, well water is very scarce in these areas. The available power supply is more than what is needed to abstract the water in the wells and 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 a larger area as water availability improves after the monsoon (Verma et al. 2005), and hence 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/pockets in the country where adoption of drip irrigation systems has undergone a 'scale', orchard crops are the most preferred crops (Dhawan 2000; Narayanamoorthy 2004b). Therefore, when farmers adopt MI systems, the crops also change, normally from field crops to fruits. 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 1–2 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.

Economic Impacts of MI Systems

There is an 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.

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 could change across systems and so are the capital costs. Also, it could 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 socioeconomic 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 3,775]; Sivanappan 1994; Narayanamoorthy 2004b). The reason for this is that the crops are high valued and even a marginal increase in yield results in a significant rise in the value of crop output. Dhawan 2000 argues that the higher value of the crop output is realized also from improved price realization due to quality improvements on one hand and the 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.

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.3,000-Rs.3,750 per ha of irrigated wheat. At the same time, a 10 % rise in the yield of pomegranate, whose minimum yield is 60,000 kg per ha per year, would result in an incremental gain of 6,000 kg/ha or Rs.90,000 per ha. Besides the incremental value of outputs, an important factor which influences the economic performance of the drip system is the cost of installation of the system.

From the point of view of deciding on the 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 there are positive externality effects on society due to 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.

Given the range of variables—physical, socioeconomic 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, socioeconomic conditions change. Now, we would examine how these variables operate changes 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 whereas in some hard-rock areas like Kolar District in Karnataka, the amount of water that the 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), and the opportunity cost of using water is high in those areas. 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. and any saving in water resulting from drip use could be treated as an economic gain. The real economic cost of pumping water would range from Rs.1.5/m^3 in North Gujarat to Rs. 2/m^3 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 [pp 3,777]). But in regions where reduction 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 precious water resources (Dhawan 2000 [pp 3,775]), resulting from reduced pumping. In situations like North Gujarat, such social benefits could not be over-emphasized.

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.12,000 for sapota and mango to Rs.28,000 for pomegranate to Rs.40,000 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.

The first level of analysis is limited to private cost-benefits (level 1). Yield increase and labor saving are the private gains here. The annual yield benefit was estimated by taking calculated daily yield increase and multiplying it by 240, which is the approximate number of days for which the fodder field yields in a year. The labor-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 a unit volume of groundwater, and the total volume of water saved. In the third level of analysis, the unit price of water in the market was treated as economic gain from the 'actual saving' of every unit of water and was added to the cost of electricity to pump a 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 labor saving. The fourth level of analysis concerns 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 constructing a storage tank and a 0.5 HP pump are added to the cost of installing the system. The private benefit-cost ratio ranged from 1.09 to 1.29; economic benefit-cost ratio (level 2), from 1.18 to 1.83; economic benefit-cost (level 3), from 1.28 to 2.78 and private benefit-cost for water buyers, from 0.88 to 1.39 (Kumar et al. 2004).

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 a primary survey on adopters and non-adopters in Kachchh, Bhavnagar, Rajkot and Banaskantha districts. 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 reduction due to crop failure and price fluctuations. While estimating the 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.

In the case of Kachchh, the B/C ratio ranges from the lowest of 0.56 for castor to 6.0 for banana. Apart from castor, there was one more crop for which the B/C ratio was found to be less than 1.0. For all other crops, the B/C ratio was more than 1.0. In the case of Banaskantha, the B/C ratio ranged from 1.37 for *bajra* to 5.2 for castor. In the case of Bhavnagar, the B/C ratio ranged from 0.84 for *bajra* to 15.3 for mango. For crops in Rajkot, the B/C ratio ranged from 1.06 for chilly to 3.3 for cotton. 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 (Kumar et al. 2004).

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 (Narayanamoorthy 1997; Sivanappan 1994). 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 even cereals 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 due to the reason that the farmers, who did not use the system faced significant yield losses due to water stress.

Potential Future Benefits from Micro-irrigation Technologies

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

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 socioeconomic 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 the crops that are served by gravity irrigation are least likely to be covered under MI systems due to physical, socioeconomic 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, water saving irrigation devices are not conducive to paddy, one of the major crops grown in these areas, too. 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 of poor quality with salinity and alkalinity, and the problems are more severe for deeper aquifers in the region. 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 major stumbling block for the adoption of sprinklers which are energy-intensive.

As regards climate, most of Gangetic-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 factors such as the physical availability of water, physical conditions of water supply and land use, cropping systems and 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; and 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 are in the downstream areas of Tapi and Narmada.

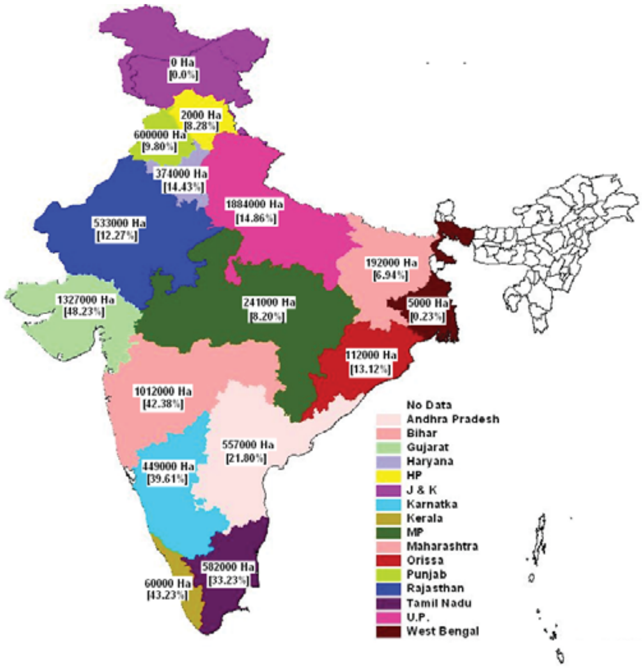
The western Ghat areas in Kerala, Karnataka, Maharashtra and Goa provide a very favorable environment for the adoption of micro-irrigation devices due to the presence of tree and fruit crops and plantation crops—coconut, arecanut, coffee, tea, mango and banana. The semi-arid, hard-rock areas of Tamil Nadu, Karnataka, Andhra Pradesh, Maharashtra and most parts of Gujarat, provide a favorable environment for the 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 as mentioned above. At the same time, there would be real saving in water due to the fact that the groundwater table is falling in these regions.

The available data on the adoption of micro-irrigation systems in different states of India during the past 4 years is a testimony to what has been discussed in the preceding paragraphs. The highest area under drip irrigation is in Maharashtra (22,358 ha). This is followed by Andhra Pradesh (17,556 ha), Karnataka (16,731 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.

Area That Can Be Brought under MI Technologies in Major Indian States

Map 1 shows the area under different crops for which MI devices are conducive in different states of India. The empirical basis for estimating this constitutes: 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 the 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.

Map 1. Estimated area under crops conducive to water saving irrigation technologies.



Note: Figures in parenthesis represent percentage area under the crop.

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

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

In order to estimate the figures for the 'total irrigated cropped area that would benefit from MI systems', we have superimposed the cropped areas for which MI systems are conducive, and the basins where MI adoption would lead to real water saving, and water productivity improvements. We would explain the logic behind this.

The earlier analysis has shown that peninsular and western India had a 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. The exception is Uttar Pradesh, which accounts for nearly 25 % of the area that is conducive to MI systems. The basins in peninsular, western and central India have favorable natural environment comprising soil, geo-hydrology and climate due to which MI system adoption can actually result in real water saving, and basin level water productivity improvement. But, in Ganga-Brahmaputra basin, in which UP is, the 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 result not in a reduction in depleted water, but a little difference in crop yields, with the resultant increase in basin level water productivity being meager. The western part of Mahanadi is another area that would be conducive to MI systems. Hence, Ganga-Brahmaputra-Meghna have to be excluded from our analysis.

Hence, the cropped areas that will benefit from MI system would 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; 3) some parts of Indus Basin covering south-western Punjab; and 4) west flowing rivers of South India. Hence, 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 socioeconomic 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 the area under those crops, which are currently rain-fed. But this analysis did not consider the several physical and socioeconomic factors that would ultimately determine the viability of drips for these crops. Whereas 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 the area irrigated by different types of irrigation systems, therefore, has not considered the physical (technical, and hydro-meteorological), and socioeconomic constraints in the adoption of MI systems.

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 by INCID and NCAP where data on water use efficiency[5] impact of drip irrigation for various crops are presented. A total of six crops, for which country-level data on the 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.

While estimating the crop area that is 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 was subtracted. The aggregate reduction in crop water requirement due to the adoption of drip systems was estimated to be 44.46 BCM (Table 1). It can also be seen that the 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 the adoption are overcome through appropriate institutional and policy environments. In the subsequent section, we would discuss what these policies are.

Table 1. Aggregate reduction in water requirement possible with drip irrigation systems.

Sr. no	Name of crop	Current yield (tonnes/ha)	Expected yield coming from the potential states* (million tonnes)	Water productivity (kg/m^3)	Improved water productivity (kg/m^3)	Water saving (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

Note: * States where MI systems are likely to be adopted. This is obtained by multiplying the average crop yield under conventional irrigation 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 INCID 1994 and NCPA 1990 as cited in Narayanamoorthy 2004b: pp 122.

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[5] We treat these water productivity values as the modified values of WUE capturing the net effect of improved water application and improved agronomic practices.

Institutional and Policy Alternatives for Spreading Micro-irrigation Technologies

The most ideal policy environment for the promotion of MI technologies in well-irrigated areas would be pro-rata pricing of electricity. While this would create direct incentive for efficient water use (Kumar 2005), the extent to which MI technologies would reduce energy use resulting in pro-rata pricing creating incentive for the adoption of MI devices depends on the crop type and the type of technology—whether pressurized system or gravity drip system—used for the crop. The reason is not all MI technologies are energy-efficient. Hence, bringing non-conventional (non-pressurized) drip systems under the ambit of 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 scenario to emerge (Kumar 2007), the government can start with metering of agricultural consumption. Cash incentives or heavy subsidy for MI devices could be provided to farmers who are willing to use them, subject to their minimizing the consumption of electricity. This cash incentive could be an inverse function of the total energy use for irrigation, and the percentage area under MI technology. This would create incentives for farmers to maximize the coverage of MI systems in their irrigated crops, particularly those which are less energy-intensive; and limit the total irrigated area.

Improving power supply conditions—both quality of power and hours of supply—is extremely important for boosting the adoption of pressurized MI devices in many areas. Such areas include alluvial North Gujarat and south-western Punjab. One could argue that with improved power supply, groundwater use could go up. But, 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. In areas where the entire cultivable land is under irrigation as in the tubewell commands of North Gujarat, and alluvial areas of central Punjab, the adoption of MI devices would result in reducing groundwater use at the farm level. MI adoption could result in farmers expanding the area under irrigation. Subsidies are required here to promote MI adoption as it would lead to social benefits from reduced stress on groundwater.

Improving the administration of subsidies is also of paramount importance to increase the welfare impacts. The farmers should be made to pay the full cost of the system initially, and subsidies released 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 so as to sustain the demand. The rural credit institutions can advance loans to farmers for the purchase of MI systems so as to maximize the coverage of 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 that the adoption of MI devices is fast, but a significant percentage of the adopters belongs to smallholder category, having less than 2.0 ha of land, and they use it for cash crops viz., cotton, ground nut, potato and vegetables.

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. An example is the sugarcane and grape grower cooperatives of Maharashtra. But, in areas where demand for drip irrigation is scattered vis-à-vis crops and geographical spread, this would be an issue. This substantiates the need for a separate agency. The agency should facilitate the 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. 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.

Summing Up

The 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 the 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 the opportunity cost of using water is zero, the saving in energy and water achieved through MI system does 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, socioeconomic 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 vis-à-vis 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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