Chapter 2
Water Saving and Yield Enhancing Micro Irrigation Technologies in India: Theory and Practice

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2.1 Introduction

Demand management is the key to the overall strategy for managing scarce water resources (Molden et al. 2001). Since agriculture is the major user of diverted water in India (GOI 1999), demand management in agriculture in the 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 2010). 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).

There are three dimensions of water productivity namely, 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 is 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 occur together with an intervention either on the agronomic or on the water control side (for discussion on other aspects of water productivity, see Kumar and van Dam 2013).

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There are several conceptual 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 during 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 depleted water and not the water applied (Kumar and van Dam 2013; 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 (Kumar et al. 2008).

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 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 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 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 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; (4) plastic mulches and tunnels; (5) improved soil moisture retention sub-surface barriers; (6) alternative wetting and drying for rice; (7) system of rice intensification; (8) direct seeding of rice; (9) aerobic rice; (10) on-farm storage; and, (11) allowing better control and timing of surface irrigation (micro-irrigation, sprinklers and their variants) (Kumar et al. 2008). But, only micro irrigation technologies are dealt with in this chapter.

A little less than 5 % of the irrigated area in the country is under micro irrigation systems. There are several constraints to adoption of MI devices. These are physical, socio-economic, financial, institutional–pricing, subsidies, extension service– and policy-related in nature (Narayanamoorthy 1997; Kumar et al. 2008). The only systematic attempt to find out the conditions under which MI systems become a

[1]See Kumar and van Dam (2013) for definitions of non-beneficial evaporation, non-recoverable deep percolation.

best bet technology, and assess the magnitude of reduction in water requirement possible through them was by Kumar et al. (2008). Such efforts are crucial from the point of view of assessing the ability to address future water scarcity problems at the regional and national level. This is an extension of their work.

The chapter aims at determining the potential benefits from the use of MI systems. This includes assessment of (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 economic benefits due to adoption of MI system. The research also aims at assessing the potential future coverage of MI systems in India, followed by a detailed analysis for Andhra Pradesh.

The chapter proceeds as follows. First, it discusses 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. In the subsequent section, a macro level analysis is done to assess the cropped areas that can be brought under water saving MI systems in the basins which would benefit from them in terms of water productivity improvements. The last section assesses the area under irrigated crops that are amenable to water-saving MI systems in erstwhile Andhra Pradesh, and the likely impact of the same on water saving in agriculture in the region.

2.2 Contribution of Micro-irrigation Technologies in Indian Agriculture

2.2.1 Present Spread of Micro-irrigation Technologies in Indian Agriculture

Table 2.1 presents the status of adoption of drip and sprinkler irrigation systems under various programmes, viz., macro management plan; technology mission on horticulture; cotton development programme and oil palm development programme. The total area covered by MI systems is 4.94 million hectares of this, nearly 38 % is under drip systems, and the remaining 62 % is under different types of sprinklers. The major crops for which drip systems are currently adopted are: cotton, sugarcane; banana, orange, grapes, pomegranate, lemon, citrus, mangoes, flowers, coconut, and a wide variety of vegetables such as cauliflower, cabbage, chilly, ladies finger and brinjal.

Sprinkler systems in the country 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 happens before the onset of monsoon when the farmers have to do sowing of these crops, or when there is a long dry spell during

Table 2.1 Area under Micro Irrigation in Indian States (2010) in ha

Name of state	Area under micro irrigation system		Total area
	Drips	Sprinklers	
Andhra Pradesh	505205	256911	762,116
Arunachal Pradesh	613	0	613
Assam	116	129	245
Bihar	301	436	737
Chhattisgarh	6360	95740	102,100
Goa	793	582	1375
Gujarat	226773	180672	407,445
Haryana	11351	533740	545,091
Himachal Pradesh	116	581	697
Jharkhand	208	742	950
Karnataka	209471	385579	595,050
Kerala	15885	3540	19,425
Madhya Pradesh	51712	143233	194,945
Maharashtra	604440	295382	899,822
Odisha	11046	33015	44,061
Punjab	17925	11414	29,339
Rajasthan	30047	866592	896,639
Tamil Nadu	153437	27834	181,271
Uttar Pradesh	12636	13310	25,946
West Bengal	247	150196	150,443
Others (NE States, Uttaranchal)	38600	45312	83912
Total	1897282	3044940	4,942,222

Source Sankaranarayanan et al. (2011)

the monsoon season. Sprinkler for groundnut is common in Saurashtra in Gujarat; for mustard in Khargaon district of Madhya Pradesh and IGNP command areas in Rajasthan. In the high ranges of Kerala and Tamil Nadu, sprinklers are used for irrigating tea and coffee plantations. However, recently, farmers use micro sprinklers and mini micro sprinklers for potato, groundnut and alfalfa.

2.3 Physical Impact of Micro-irrigation Technologies on Water Demand for Crop Production[2]

Analysis of the potential impact of MI systems on the aggregate demand for water in crop production warrants three important considerations. The first concerns the extent of coverage that can be achieved in MI system adoption at the country level.

[2]This section draws heavily from Kumar et al. (2008), but is also updated with latest research.

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 are closely 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 extent of water saving possible at the aggregate level. But, 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. 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 a latent 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 lead to over-estimation of the potential coverage of MI systems and the extent of possible water-saving with MI adoption. These complex questions are addressed in the subsequent sections of this chapter.

(A) **Physical constraints and opportunities for adoption of MI Systems**

Where potential exists, the coverage that can be attained by MI system adoption requires a systematic identification of the conditions that are favourable including geographical assessment of areas. Such conditions can be physical, socio-economic or institutional. They 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 evapotranspiration 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). However, their adoption is very much limited in India. This includes even areas where the capital investment for creating irrigation source is very high (For example: 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, there is no synchronization between water delivery schedules followed in canal irrigation and that to be followed for MI systems. 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 to match with the evapotranspirative demand. This means, intermediate storage systems are 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 to lift water from the storages and running the MI systems. These two investments would reduce the economic viability of MI.

Therefore adoption of MI would be largely restricted to areas irrigated by wells. However, 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 in Bihar and western Orissa, and where economic access to water is a problem. It is difficult for these farmers to adopt 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 is not with individual farmers but with groups. Also, a large number of farmers have to depend on water purchases. They get water through underground pipelines at almost negligible water pressure. 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. The farmers who are either water buyers or share users of 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 deposit 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* (citrus) orchards. These farmers can also use this water for drip irrigation to prevent problems of clogging.

In addition to areas irrigated by groundwater, there are hilly areas of the western and eastern Ghat, 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 m. 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.

Geological setting has a strong influence on MI adoption in well-irrigated areas. In hard rock areas of Maharashtra, Madhya Pradesh, Tamil Nadu, Karnataka and Andhra Pradesh, farmers will have strong incentive to go for MI systems. The reason is dug wells and bore wells in hard rock areas 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 will have to discontinue pumping after 2–3 h for the wells to recuperate. When pressurized irrigation systems are used, the rate at which water will be pumped will reduce. This will also give 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 could be expanded. This factor provides a great economic incentive for farmers to adopt water-saving micro irrigation systems.

(B) **Socio-economic and institutional constraints for MI adoption**

Another major constraint in adoption of conventional MI technologies is the predominant cropping pattern in the water-scarce regions. MI systems are best suited 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 returns farmers get as the saving in input costs are not very significant (Kumar et al. 2004). But, percentage area under horticultural crops is very low in these regions, except Maharashtra. The total area under horticultural crops and vegetables is only 5.04 % 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).

Though the low cost drip irrigation systems appear to be attractive, they have low physical efficiency when used for crops in which the plant spacing is small (chilly, vegetables, groundnut and potato). In such situations, they also score low on 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 commonly grown. 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 observed. 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 new approaches.

Further, 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 going down. Certain studies of 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 field scale adoption. Adopting suitable cropping patterns that would improve the adoptability of water saving technologies is one good 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 the fact that small and marginal farmers account for large percentage of the operational holders in India, the future adoption 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, papaya). It will be extremely difficult for the farmers to block their piece 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 price of those fruits. Labour absorption is another major issue when traditional crops such as paddy, which are labour-intensive, get replaced by orchards. Orchards require less seasonal labour 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).

Poor rural infrastructure and power connections to agro wells along with poor quality of power supply, is yet 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 requiring 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 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 result in private benefits.

Un-scientific water delivery schedules followed in surface irrigation systems, and power supply restrictions for farm sector also cause constraints for MI adoption. It is common in surface irrigation systems that while plenty of water is released for the crops for some parts of the season, in the last stages 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 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 provided by concerned agencies pose another important bottle-neck. 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. 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 operates against the promotion of 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 of the subsidy benefits, sans maintenance. The suppliers do not offer any after-sales services to the farmers and hence are not interested in ensuring quality control. The systems being supplied are often of sub-standard quality. Over and above, as the amounts of funds available for subsidies are limited, the smartest of farmers take the benefit. On the other hand, the government officials, who inspect the systems installed, only check the amount of materials supplied, to 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 it is the opportunity cost of using water, which influences farmers' decision, 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 one's 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 farmer gets by introducing MI systems are from the increased crop yield. This will not happen unless the farmer adopts new agronomic practices (Kumar and Singh 2001).

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 being that the economic efficiency of water use for the irrigated crops grown in the area even with the 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 restrains those who like to adopt MI systems. 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 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 neighbouring 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 in 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 amount of water consumed by the crop to the amount of water applied. This method does 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 in 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 un-consumed water is not lost in natural sinks like saline aquifer or swamps (Allen et al. 1998). 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 as a component of the available water resources (Keller et al. 1996; Perry 2007), 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, (2) the type of crops; (3) climate; and (4) type of MI technology.

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 reason is that the depth of groundwater table is in the range of 20–135 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 (Ahmad 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 m 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 (Kumar et al. 2008). Though many water saving practices have evolved over time in paddy irrigation, their water saving potential is also questionable (Perry 2007).

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 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 canopy cover is small (Kumar et al. 2008; Kumar and van Dam 2013).

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 (Kumar et al. 2008).

The water saving impacts will be generally higher for drips than sprinklers. With drip irrigation, water could be directly applied to plants, preventing non-beneficial evaporation. This will not be possible with sprinklers, as they would wet the entire field instead of the plant roots. Hence, the reduction in non-beneficial evaporation from soils and non-recoverable deep percolation, and hence actual water saving through micro irrigation depend on the type of crops and the natural environment (Kumar and van Dam 2013).

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

The extent of water saving at system and basin level because of the widespread adoption of MI systems is widely debated. The debate centers around (1) the real water savings at the field level; and, (2) 'what farmers do with the saved water'. We have addressed the first question in the earlier section. As regards the second question, many believe that the aggregate impact of drips on water use would be similar to what it makes 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), and therefore the net effect of 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 some 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 which influence farmers' decision making with regard to area to be brought under irrigated cultivation, 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 of these factors is the overall availability of groundwater in an area; and the power supply 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 adoption of conventional WSTs, farmers would expand the area under irrigation. Let us examine 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 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 irrigate only 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. 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 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 of 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 results in reduced aggregate water demand.

On the other hand, if the availability of water in wells is less than what the available power supply can extract, the farmers are tempted 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. In such a scenario, 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. 2004), 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 2004). Therefore, while farmers adopt MI systems, the crops also change, normally from field crops to fruits.

Farmers bring about significant changes in the cropping systems of farmers with the adoption of drips. When drips are adopted for orchards, farmers are found to permanently abandoning cultivation of traditional crops such as paddy and wheat. An 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 towards the close 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.

While for many fruit crops, the gestation period is very large extending from 3 to 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.

A research study was carried out the hydrological and farming system impacts of MI technologies in north Gujarat. The study involved a survey of 114 adopter families and 51 non-adopters, using stratified random sampling, and collection of primary data of their farming systems in detail. In the case of adopters, the survey included both pre and post adoption scenario. The most important and interesting findings of the study was that MI system adoption is associated with cropping pattern shifts. With MI adoption, several of the traditional cereal crops were replaced by cash crops amenable to MI systems. While the irrigation water use rates for individual crops reduced, the aggregate cropped area also reduced. The yield of most crops increased due to MI adoption. There has been substantial increase in water productivity of individual crops, in both physical and economic terms post MI adoption. Further, in spite of all these changes, the groundwater use for irrigation reduced significantly at the farm level by nearly 7527 m^3 per farm (Kumar et al. 2010).

2.4 Economic Impacts of MI Systems

For a given crop, the yield as well as water-saving benefits of MI system could change across different systems, so are the capital costs. Also, it could change along with crops cultivated. But, the research is 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. This is explained 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). 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.

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 per ha. of irrigated wheat. At the same time, a 10 % rise in yield of pomegranate, whose minimum yield is 60,000 kg per ha. per year, would result in an incremental gain of 6000 kg/ha. or Rs. 90,000 per 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 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 externalities on the 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. 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 would examine how the way these variables operate 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), 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.

Coming to the benefits from 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/m^3 to Rs. 2.5/m^3 in north Gujarat to Rs. 6/m^3 in Kolar) as the economic value of water then 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). 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), 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 was 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 was limited to private cost-benefits. Yield increase and labour saving are the private gains here. The annual yield benefit was estimated by taking calculated daily yield increase 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 h) and multiplying it by the daily wage.

In the second level of analysis, the actual economic cost of using every unit of electricity was considered as a benefit from saving every unit of the energy. 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. 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. 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 was 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. 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.

An analysis of economics of some water-saving technologies was attempted on the basis of data on crop inputs and outputs, and capital investments collected from primary survey of adopters and non-adopters for Kachchh, Bhavnagar, Rajkot and Banaskantha districts. The analysis was 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 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.

On the whole it was found 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 (Kumar et al. 2004). This is in conformation with the work of earlier researchers (see Narayanamoorthy 1997). 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.

The data available from field research carried out in north Gujarat, involving 114 adopter farmers, was used in working out the benefit-cost analysis of MI-systems for select plots, in which crop shift has not taken place after adoption. The results showed significant variations in B-C ratio across crops from as low as 0.72 to a highest of 5.96. It was found that most farmers simultaneously changed the crop with introduction of MI system. Therefore, the findings emerging from analyses, wherein the crop is expected to remain the same after adoption, have very limited practical and policy relevance (Kumar et al. 2010). In real life situations, MI adoption is associated with selection of high valued crops for which MI systems are the best bet technology (Kumar et al. 2008), and as a result the incremental benefits would far exceed our estimates (Kumar et al. 2010).

2.5 Potential Area Under Different Water Saving MI Technologies in India[3]

For adoption of water saving MI systems, the following conditions need to be satisfied: (1) technical feasibility; and (2) socio-economic viability. The technical feasibility of adoption of MI systems is determined by the following factors (1) the presence of irrigation system which can delivery water to the crop under pressure for running the MI system; (2) the availability of good quality water, or water free from high TDS; (3) scarcity of water for irrigation in the region; and (4) farmers have independent source of water for irrigation.

The three factors which determine the socio-economic viability of MI systems are: (1) presence of crops that are amenable to water saving MI systems; (2) degree of rural electrification; and (3) power supply regime. As regards the first point, Kumar et al. (2008) identified the crops in different regions of India, which are amenable to MI systems. We have refined these estimates by incorporating a few new cash crops, and also taking into account the change in irrigated area under different crops that are amenable to water saving MI systems as on 2010. As regards the second factor, for well owning farmers to adopt MI systems, it is necessary that the wells are electrified. This is because electricity for farming is subsidized, which would bring down the operating costs within affordable limits. Conversely, using diesel engines to pump water and to pressurize the MI system would be prohibitively expensive, as farmers would have to pay for higher capacity engines and sometimes higher fuel consumption.

As regards the third factor, most MI systems are energy intensive, requiring more electricity to pump out a unit volume of water as compared to the traditional method of irrigation. Whereas the biggest benefit from MI is water saving. In rich alluvial areas (such as Punjab, Haryana, Uttar Pradesh, Bihar, Assam and most parts of West Bengal) daily power supply availability is for lesser number of hours than what the energized wells can run. Or in other words, power shortage limits the ability of the well owners to expand the area under irrigation. In such situations, the incentive to go for MI systems will be limited. Whereas in hard rock regions, the power supply is available for more number of hours than what is need to pump out water from the wells, or groundwater scarcity limits farmers ability to expand area under irrigation. Under such situations, the farmers would have strong economic incentive to adopt MI systems, as they would be able to expand the area under irrigation.

In order to estimate the potential area that can be brought under MI system, we followed the following steps: (1) mapped irrigated areas of crops which are amenable to water saving MI systems in major Indian states; (2) deduced areas that are potentially under well irrigation, by multiplying the gross irrigated area under such crops in each state by the ratio of the net groundwater irrigated area and the total

[3]This section is based on a report titled "*Micro Irrigation Business in India: Potential, Challenges and Future Prospects*," prepared by IRAP for Infrastructure Development Finance Company Ltd., Mumbai, July 2012.

(canal, tank and well) net area irrigated; (3) deduced irrigated crop areas which are falling in water-scarce river basins, by eliminating areas that are either falling in water-rich basins (such as the Ganges and Brahmaputra) or have poor rural electrification, or areas that are having rich groundwater but facing severe power shortage.

In order to make an assessment of the extent of energisation of agricultural wells in different states of India, the data on number of pump sets which are used for irrigation and the total annual agricultural power consumption were collected and analyzed. The results vis-à-vis the total number of agricultural pumps and the average energy use by the pumps, show that agricultural power connections is very high in states such as erstwhile AP, Gujarat, Maharashtra, Madhya Pradesh, Punjab, Rajasthan, Karnataka and Tamil Nadu. Though UP had nearly 0.85 million electric pump sets, it is a small percentage of the total no. of agro wells in the state. Though Kerala also has a considerable number of electrified wells, most of the wells are part of the homestead and these wells are also used for domestic purpose. The physical feasibility of using these wells for irrigating crops in the farm will be very poor.

As a coincidence, the states which are falling in water-rich basins also suffer from poor infrastructure conditions such as low level of rural electrification. They are West Bengal, Uttar Pradesh, Bihar and Assam. Majority of the irrigators in these states either depend on diesel engines for pumping groundwater or purchased water from electric or diesel well owners. While demarcating the area under MI systems, the area under irrigated paddy was not considered at all as use of micro irrigation system for paddy has yet not been proved to be beneficial. Further, only field crops were considered for sprinkler irrigation systems, and all row crops were considered for drip irrigation.

Table 2.2 gives the estimated potential area under drip irrigation and sprinkler irrigation for major Indian states, covering a total of 16 states, which are important from the point of view of agricultural production in the country. It gives the total area suitable for MI. It also gives the potential areas for MI adoption where conditions are favourable in terms of power connections, and water scarcity is likely to drive MI system adoption.

However, these figures do not mean that adoption of any type of MI system would lead to water saving even at the plot level. Especially in the case of sprinkler irrigation, which are considered only for field crops here, the extent of water saving is likely to be negligible. This is because soil evaporation (from the soil which is not covered by crop canopy), which is a non-beneficial component of the consumed fraction of irrigation water applied in the field (Perry 2007), is likely to remain same under sprinkler method of irrigation as in the case of traditional method of irrigation. While some reduction in non-recoverable deep percolation, which can be treated as part of the total consumptive use (Allen et al. 1998; Kumar and van Dam 2013), would be possible through sprinkler usage, such benefits would be highly situation specific. One such situation is desert soils with undulating land, where conventional method of irrigation could result in poor distribution uniformity, depression storage and deep percolation of water in the head reaches of the field. Here again, the real impact of sprinklers could be in the form of improved yield resulting from better distribution uniformity, rather than water saving.

Table 2.2 Potential area for water saving micro irrigation systems in India

Name of state	Area suitable for drip system ('000 ha)	Potential area* for drip system ('000)	Area suitable for sprinklers ('000 ha)	Potential area* under sprinklers ('000 ha)
(Erstwhile) Andhra Pradesh	879.66	879.66	385.56	385.56
Bihar	214.59	0.00	1713.27	0.00
Chhattisgarh	20.86	20.86	42.72	42.72
Gujarat	2021.25	2021.25	1422.19	1422.19
Haryana	381.64	381.64	2130.34	2130.34
Jharkhand	42.00	42.00	32.48	32.48
Karnataka	766.85	766.85	644.35	644.35
Kerala	60.00	60.00	0.0	0.0
Madhya Pradesh	413.44	413.44	4228.92	4228.92
Maharashtra	1305.16	1305.16	1312.53	1312.53
Odisha	145.40	145.40	75.8	75.8
Punjab	546.04	546.04	3022.2	3022.2
Rajasthan	677.84	677.84	4471.82	4471.82
Tamil Nadu	646.24	646.24	167.44	167.44
Uttar Pradesh	2222.27	0.00	9269.07	0.0
Uttaranchal	79.73	79.73	165.49	165.49
West Bengal	781.47	0.00	540.36	0.00
Total area MI	11204.0	7986.0	29624.0	18101.0

*Note** While estimating potential areas for micro irrigation, the areas where water saving benefits are likely to be accrued, are only considered. Hence, areas in the states of UP, Bihar, and West Bengal are not considered

Source Authors' own estimates based on secondary data on irrigated area under different crops, in different states (Indiastat.com); IRAP (2012)

Hence, from the point of view of water saving, we can consider 7.98 million hectares as the potential area under MI systems.

2.6 Can Drip Irrigation Solve Water Scarcity Problems in Andhra Pradesh?

Expectations were raised regarding the potential of drip irrigation in erstwhile Andhra Pradesh, with the task force on micro irrigation set up under the Chairmanship of Chandra Babu Naidu, former Chief Minister of erstwhile Andhra Pradesh. But, there has been no scientific assessment of the real potential for drip irrigation in the state, which involved data on the cropping systems that exist in different regions of the state, and due consideration to the conditions under which drip system becomes the best bet technology. Researchers have argued that the drip irrigation systems would become best bet technologies when they are adopted in areas with semi-arid and arid climate with deep water table conditions, for row crops, and under well or lift irrigation. Further, it was argued that the water saving benefit of drip irrigation will be significant under semi-arid and arid climates when used for row crops, and in areas with deep unsaturated zones. The technical feasibility and economic viability of drip irrigation would be higher for well-irrigated crops, with independent pressurizing devices; and also their economic viability better for distantly spaced crops, for which the capital cost of the system would be less.

Unfortunately, none of these issues were given adequate attention while assessing the potential of drip irrigation systems in the state. As cursory look at the irrigation landscape of the state would show that nearly 3.84 million hectares out of the total 6.28 million hectares of the irrigated land is under paddy, i.e., 61 %. One has to exclude this area, while thinking about drip irrigation systems. The crops that are amenable to micro irrigation systems and that are grown extensively in Andhra Pradesh are groundnut, chilly, cotton, sugarcane, cotton and tobacco. They together accounted for a total area of 10.08 lac hectares (Table 2.3). Among these crops, groundnut is actually gives better results under micro sprinklers, and not drips. Nevertheless, it is also considered in view of the water-saving benefit it can give, when irrigated with the use of MI systems. Since some of these crops are also grown in canal command area, MI system adoption will be difficult there. This further reduced the potential of MI systems in the state. The potential area under crops that are conducive to water saving MI technologies, wherein the intended benefits could be derived, in the state was estimated to be only 0.879 million hectares.

Finance is going to be another major impediment for MI adoption. The actual record of MI adoption in the state is a true reflection of these structural constraints facing adoption of drip systems. Under the much-publicized Andhra Pradesh Micro Irrigation project of the government of AP, a total area of 1.66 lac hectares was covered under MI systems over a time period of nearly 30 months. The total subsidy benefit to farmers was to the tune of 209.96 crore rupees, which works out to be Rs. 18,070 per ha. (Kumar and van Dam 2009). The result is that most of the farmers have installed drip systems for fruit crops, for which returns, as noted by Dhawan (2000), would anyway be high even without drips, and sprinklers which

Table 2.3 Area under crops amenable to micro irrigation systems (as on 2008–09)

Name of crop	Area irrigated ('000 ha)	(%) share
1. Groundnut	294.0	27.1
2. Chilly	169.0	15.6
3. Sugarcane	318.0	29.4
4. Cotton	255.0	23.5
5. Tobacco	47.0	4.3
Total area under crops	1083.0	100.0

Source Based on irrigated cropped area in AP in 2004–05, as cited in Reddy (2007) are low cost but not technically efficient for small farms (Kumar et al. 2008). Crops such as sugarcane, chilly and groundnut would require much higher capital investment for installing drip systems as compared to the fruit crops like sweet lime. By 2010, an area of 0.505 m. ha was under drip irrigation in erstwhile AP. This much needed investment is least likely to come from farmers given the current mode of pricing of electricity and water followed in the farm sector, which does not create any incentive for farmers to save water (Kumar et al. 2008).

While assessing the water saving impact of MI systems, more caution needs to be exercised. Nearly 85 % of the area of erstwhile AP is underlain by hard rock aquifers, comprising crystalline formations and basalt with limited groundwater potential. Wells are the major source of irrigation in these areas. But, due to scarcity of groundwater, only a small percentage of the cultivated area is irrigated in these regions. A major proportion of the area under cash crops, which are amenable to MI systems, is located in these regions. It is quite likely that with the adoption of MI, farmers would expand the area under irrigation in these regions, as increased area under irrigation production is a major economic incentive for adopting MI. Because of this reason, the real economic returns from the use of MI systems can be captured only if we analyze the changes in the farming system of the adopter households.

2.7 Conclusions

The future potential of MIS 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 MIS in those basins. Creating appropriate institutions for extension, designing water and electricity pricing policies apart from building proper power supply infrastructure would play a crucial role in facilitating large-scale adoption of different MIS. The real potential for adoption of MI systems in erstwhile AP, for crops wherein real water saving at the field level is possible, appears to be limited. Further limited is the scope for saving water at the farm level, as it is quite likely that farmers would expand the area under irrigation after adoption of MI system.

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