# Drip and Sprinkler Irrigation in India: Benefits, Potential and Future Directions

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## Background

Water is becoming increasingly scarce worldwide and more than one-third of the world population would face absolute water scarcity by the year 2025 (Seckler et al. 1998; Seckler et al. 1999; Rosegrant et al. 2002). The worst affected areas would be the semi-arid regions of Asia, the Middle-East and sub-Saharan Africa, all of which are already having a heavy concentration of population living below poverty line. The situation in India is also critical, where absolute water scarcity is already affecting a substantial part of the population and this proportion is increasing rapidly (Amarasinghe et al. 2005, 2007).

Much of the water scarcity in India is due to spatial variation in demand and supply of water. Irrigation, is the largest water consuming sector, accounting for more than 80 % of the total withdrawals. Yet, irrigation so far has covered only about 40 % of the gross cropped area, even though India has the largest irrigated area in the world. Given the increasing scarcity and also nonagricultural water demand, demand management is receiving special attention. In India, although a number of demand management strategies in the irrigation sector have been introduced with a view to increasing the water use efficiency (Vaidyanathan 1998; Dhawan 2002), however the net impact of these strategies in increasing the water use efficiency so far has not been very impressive. One of the demand management strategies introduced relatively recently to manage water consumption in Indian agriculture is micro-irrigation (MI). Unlike flood method of irrigation (FMI), micro-irrigation supplies water at the required interval and in desired quantity at the location where water is demanded using a pipe network, emitters and nozzles. Therefore, MI in principle should result in low conveyance and distribution losses and lead to higher water use efficiency.

Among advanced micro-irrigation (MI) techniques, drip and sprinklers are gaining special attention. Drip irrigation (DIM) and sprinkler irrigation (SIM) methods have distinct characteristics in parameters such as flow rate, pressure requirement, wetted area and mobility (Kulkarni 2005), but they have the potential of significantly increasing water use efficiency. While DIM supplies water directly to the root zone through a network of pipes and emitters, SIM sprinkles water, similar to rainfall, into the air through nozzles which subsequently breaks into small water drops and fall on the field surface. DIM has little or no water losses through conveyance (INCID 1994; Narayanamoorthy 1996, 1997; Dhawan 2002), and the on-farm irrigation efficiency of a properly designed and managed drip irrigation system can be as high as 90 %, compared with 35 to 40 % efficiency in surface method of irrigation (INCID 1994). However, SIM has relatively less water saving (up to 70 % efficiency), since it supplies water over the entire field of the crop (INCID 1998; Kulkarni 2005).

Besides higher water use efficiency, MI has other economic and social benefits too. Research station experiments show MI increases productivity by 20 to 90 % for different crops (INCID 1994, 1998); reduces weeds, soil erosion; cost of cultivation, especially in labor-intensive operations; energy use (electricity) for operating irrigation wells due to reduced water consumption (Narayanamoorthy 1996 and 2001).

Studies show MI has an enormous potential in India, where DIM and SIM can cover about 80 crops (overview of MI development in INCID 1994 and 1998). DIM is highly suitable for wide spaced crops, but it is also being used for cultivating oilseeds, pulses, cotton and even for wheat crop. SIM is mostly suitable for closely grown crops like cereals, pulses, wheat, sugarcane, groundnut, cotton, vegetables, fruits, flowers, spices and condiments. An experimental study suggests that sprinklers can also be used successfully for cultivating paddy crop (Kundu et al. 1998). Unlike conventional method, MI also has the advantage of irrigating undulating terrain, rolling topography, hilly areas, barren land and areas which have shallow soils (Sivanappan 1994). In spite of many advantages, MI coverage in India, except in a few states, is not appreciable. High capital investments (ranging from Rs. 20,000 to 55,000 per hectare depending upon the nature of crops and the material to be used), little or no cost of surface irrigation supplies; free electricity for pumping groundwater have been the important impediments for faster adoption of MI techniques. However, an increase in the DIM adoption has taken place since the 1980s, mainly as a result of various promotional programmes introduced by the Central and State Governments (Narayanamoorthy 2005).

In spite of the enormous potential for different crops, not many studies seem to have been undertaken to analyse the potential and prospects of drip and sprinkler irrigation for different states in India. This paper, using the available secondary information, attempts to fill this void. The specific objectives of the study are: (a) to assess the past trends in drip and sprinkler irrigated area across states; (b) to estimate the potential area for drip and sprinkler irrigation in different states; and (c) to suggest policies for increasing the adoption of WSTs in the future.

## Trends in Area under Drip and Sprinkler Irrigation[1]

DIM and SIM adoption in India are not the same across crops and regions. While DIM is largely found in states like Maharashtra, Andhra Pradesh and Tamil Nadu, SIM is largely adopted in states like Haryana, Rajasthan and Madhya Pradesh (INCID 1994, 1998; GOI 2004).

[1] One of the serious constraints faced by the researchers working on micro-irrigation is the data availability. Though most of the area currently cultivated under micro-irrigation is established through various government sponsored schemes, coverage of area under MI by states and by crops are seldom published by any single agency. This does not allow the researchers to study the trends and determinants of micro-irrigation across states in a detailed manner. This section is written with great data constraint.

Crops that are cultivated with these two methods of irrigation are also not the same. As already mentioned, wide spaced crops are highly suited for DIM, whereas close spaced crops are suitable for SIM. Therefore, we asses the DIM and SIM trends separately.

The development of DIM was very slow initially, but its spread increased significantly since 1990s due to various promotional schemes introduced by the Government of India and states like Maharashtra. DIM area increased from a mere 1,500 ha in 1985 to 70,589 ha in 1991-92, and to 2,46,000 ha in 1997-98 (INCID 1994; AFC 1998). As of 2003, the DIM area has increased to about 450 thousand hectares, of which 78 % of the area is under Government of India Schemes. However, as mentioned in the Report of the Task Force on Micro-irrigation, a large number of institutions, commercial organisations, universities, large public/private sector companies, NGOs, etc., have taken up drip irrigation in the country for their farms/crops, which are estimated to be of about 1, 00,000 ha in area. This area has not been reflected in the estimate made by the government departments. Therefore, the total DIM area in the country could be as high as 500,000 hectares as of March 2003 (GOI 2004).

Drip irrigated area has increased substantially in the 1990s across almost all the Indian states (Table 1). During all the three time periods studied, Maharashtra State alone accounted for nearly 50 % of India's total drip irrigated area, followed by Karnataka, Tamil Nadu and Andhra Pradesh. However, DIM area still constitutes a very small proportion of the total irrigated area in all the states in India - only 0.48 % of the gross irrigated area and about 1.09 % of the gross groundwater irrigated area in 2000-01.

Although DIM technology can be applied to over 80 crops in India, its use so far has been limited to only a few crops. As of 1997-98, coconut, grapes, banana, citrus, mango and

**Table 1.** State-wise area under drip method of irrigation.

| State | Area ('000 ha) | | | Percent of total area | | |
|---|---|---|---|---|---|---|
| | 1991-92 | 1997-98 | 2000-01 | 1991-92 | 1997-98 | 2000-01 |
| Maharashtra | 32.9 | 122.9[a] | 160.3 | 44.64 | 50.00 | 53.16 |
| Karnataka | 11.4 | 40.8[b] | 66.3 | 16.17 | 16.58 | 18.03 |
| Tamil Nadu | 5.4 | 34.1 | 55.9 | 7.59 | 13.86 | 15.20 |
| Andhra Pradesh | 11.6 | 26.3 | 36.3 | 16.41 | 10.70 | 9.88 |
| Gujarat | 3.6 | 7.0 | 7.6 | 5.05 | 2.85 | 2.07 |
| Kerala | 3.1 | 4.9 | 5.5 | 4.30 | 1.98 | 1.50 |
| Orissa | 0.1 | 2.7 | 1.9 | 0.06 | 1.10 | 0.52 |
| Haryana | 0.1 | 1.9 | 2.1 | 0.17 | 0.77 | 0.55 |
| Rajasthan | 0.3 | 1.6 | 6.0 | 0.43 | 0.65 | 1.63 |
| Uttar Pradesh | 10.1 | 1.5 | 2.5 | 0.16 | 0.61 | 0.68 |
| Punjab | 0.1 | 1.1 | 1.8 | 0.03 | 0.45 | 0.49 |
| Other States | 2.2 | 1.1 | 5.4 | 3.00 | 0.47 | 1.47 |
| Total | 70.6 | 246.1 | 367.7 | 100.00 | 100.00 | 100.00 |

*Source:* AFC 1998 and GOI 2004

*Note*: a- includes state subsidy scheme area of 58498 ha; b- includes area under central and state schemes for development of oil palm and sugarcane.

pomegranate together accounted for 67 % of the total DIM area. Maharashtra, Andhra Pradesh, Tamil Nadu and Karnataka account for a major share of the area of the above crops. For example, Maharashtra alone accounted for 93 % of the 26,460 ha of the banana area under drip irrigation. It clearly suggests that despite having severe water scarcity in different regions, the adoption of the drip method of irrigation is only concentrated in a few states.

Sprinkler irrigation method is relatively old for Indian farmers as compared with drip irrigation method. Sprinkler was introduced in India during the mid-1950s for plantation crops like coffee and tea. Over the years, SIM spread into large areas in states like Haryana, Rajasthan, MP, Maharashtra and Karnataka. Unlike DIM, detailed and accurate statistics are lacking for sprinkler irrigation. The gross area under sprinkler irrigation has increased from 0.23 mha in 1985 to 0.67 mha in 1998. According to the National Committee on Plasticulture Applications in Horticulture (NCPAH), the total SIM area is estimated to have increased to 1.63 mha. This is almost 300 % higher than the present area under drip method of irrigation. SIM adoption across states also vary, it is mainly concentrated in the central and the northern part of the country (Table 2). In 2004-05, Haryana, Rajasthan, West Bengal and Maharashtra together accounted for 70 % of India's total SIM area.

**Table 2**. State-wise area under sprinkler irrigation: 1997-98 and 2004-05.

| States | Area ('000 ha) | | Percent to total area | |
|---|---|---|---|---|
| | 1997-98 | 2004-05* | 1997-98 | 2004-05* |
| 1. Madhya Pradesh | 149.9 | 85.0 | 22.78 | 5.20 |
| 2. West Bengal | 120.0 | 135.0 | 18.23 | 8.26 |
| 3. Assam | 90.0 | 125.0 | 13.67 | 7.65 |
| 4. Haryana | 83.6 | 490.0 | 12.70 | 29.97 |
| 5. Rajasthan | 47.8 | 425.0 | 7.27 | 25.99 |
| 6. Karnataka | 41.9 | 125.0 | 6.36 | 7.65 |
| 7. Maharashtra | 33.1 | 110.0 | 5.03 | 6.73 |
| 8. Tamil Nadu | 32.1 | 10.0 | 4.88 | 0.61 |
| 9. Gujarat | 27.7 | 11.0 | 4.21 | 0.67 |
| 10. Andhra Pradesh | 17.1 | 55.0 | 2.60 | 3.36 |
| 11. Uttar Pradesh | 7.4 | 10.0 | 1.12 | 0.61 |
| 12. Kerala | 5.8 | 8.0 | 0.88 | 0.49 |
| 13. Bihar | 0.2 | 0.5 | 0.02 | 0.03 |
| 14. Himachal Pradesh | 0.1 | 0.3 | 0.01 | 0.02 |
| 15. Jammu & Kashmir | 0.03 | 0.2 | 0.00 | 0.01 |
| 16. Orissa | 0.4 | 12.0 | 0.06 | 0.73 |
| 17. Punjab | 0.2 | 10.0 | 0.03 | 0.61 |
| 18. Others | 0.5 | 23.1 | 0.08 | 1.41 |
| Total | 658.5 | 1,634.9 | 100.00 | 100.00 |

*Source:* INCID 1998 and NCPAH 2005

*Note:* * - Figures are approximate, estimated based on the graph provided by NCPAH

The reasons for the large-scale adoption of sprinkler irrigation vary from state to state. Though MP receives medium rainfall, it is irregular and the summer has long dry spells. This encourages MP farmers to adopt sprinkler irrigation for crops like soybean in various parts of the state. In Haryana, the soil condition, topography and the climates that are prevailing in the south western part of the state, especially in districts of Bhiwani, Mahindergarh, Rothak, Sirsa and Hisar, have prompted the adoption of sprinkler irrigation. Similarly, favorable cropping patterns for MI and water scarcity during the summer season are the main reasons for the relatively higher adoption of sprinkler irrigation in Rajasthan (INCID 1998).

Although the SIM reported area is much higher than that under drip irrigation, no reliable data is available on the composition of crops that are cultivated presently using this method of irrigation. The INCID 1998 report presents a whole lot of information about the sprinkler method, but does not provide where and what crops are cultivated under this method. In fact, reliable and time series data on micro-irrigation is seldom available even for research purpose. Agencies involved in promoting MI should make all efforts to publish data on the development of micro-irrigation in terms of crop composition, area by state, districts and different size classes, area by state promoted schemes and other schemes. This would help one to analyse the underlying factors and suggest possible ways and means to increase the adoption of such water saving technologies.

## Potential Areas for Drip and Sprinkler Irrigation in India

In spite of the large capital investments, MI seems to generate better returns for farmers, even without government subsidies (Table 3). Although micro-irrigation has proved to be a very useful method for efficient use of irrigation water, not many studies have attempted to estimate the total potential area for drip and sprinkler method of irrigation for different states in India. Therefore, in this section, we try to estimate the total potential area for drip and sprinkler irrigation methods across different states in India.

Before presenting our own estimates, we first discuss the estimates of potential DIM and SIM l area on the basis of available literature. Two estimates are available as the potential DIM area - 18.2 Mha by NCPA 1990, and 27.0 Mha by the Task Force on Micro-Irrigation (TFMI) (GOI 2004). The potential SIM area estimates vary, from 42.5 Mha of INCID 1998 to 69.5 Mha of TFMI, (Table 4). What could be the possible reasons for such wide variation in these estimates? It appears that there are some methodological problems with the available estimates. It is not clear whether the estimates include irrigated cropped area alone or both irrigated plus un-irrigated cropped area. It also appears that the TFMI estimate includes both irrigated and un-irrigated cropped areas (example cotton area). Since water sources are needed to use micro-irrigation, one should not include un-irrigated cropped area while estimating potential area for drip and sprinkler irrigation.[2] Moreover, both the estimates have not provided

[2] Potential area for MI can be estimated in various ways using different assumptions. If one wants to include un-irrigated crops that are suitable for MI for estimation, it is essential to specify under what condition this would be possible. In any case un-irrigated crop area may not be immediately brought under the method of MI.

**Table 3.** Field survey results of drip irrigation: banana, grapes and sugarcane.

| Particulars | Crop's name | Method of irrigation | | Benefit over FIM | |
|---|---|---|---|---|---|
| | | DIM | FIM | In percent | In value |
| Water consumption (HP/hours/ha) | Banana | 7,884.70 | 11,130.30 | 29.20 | 3245.60 |
| | Grapes | 3,310.40 | 5,278.40 | 37.30 | 1968.00 |
| | Sugarcane | 1,767.00 | 3,179.98 | 44.43 | 1412.98 |
| Productivity (quintal/ha) | Banana | 679.50 | 526.35 | 29.10 | 153.20 |
| | Grapes | 243.25 | 204.29 | 19.10 | 38.96 |
| | Sugarcane | 1,383.60 | 1,124.40 | 23.05 | 259.20 |
| Electricity consumption (Kwh/ha) | Banana | 5,913.33 | 8,347.75 | 29.16 | 2,434.42 |
| | Grapes | 2,482.77 | 3,958.78 | 37.28 | 1,476.01 |
| | Sugarcane | 1,325.25 | 2,384.99 | 44.43 | 1,059.74 |
| Water use efficiency (HP hours/quintal) | Banana | 11.60 | 21.10 | 45.10 | 9.50 |
| | Grapes | 13.60 | 25.80 | 47.30 | 12.20 |
| | Sugarcane | 1.28 | 2.83 | 5.48 | 1.55 |
| Cost of cultivation (Rs/ha) | Banana | 51,437 | 52,740 | 2.50 | 1303 |
| | Grapes | 1,34,506 | 1,47,915 | 9.10 | 13,409 |
| | Sugarcane | 41,993 | 48,540 | 13.49 | 6,547 |
| Gross income (Rs/ha) | Banana | 1,34,044 | 102935 | 30.22 | 31,109 |
| | Grapes | 2,47,817 | 211038 | 17.40 | 36,779 |
| | Sugarcane | 106366 | 85,488 | 24.00 | 20,878 |
| Capital cost of drip-set (Rs/ha)(without subsidy) | Banana | 33,595 | — | — | — |
| | Grapes | 32,721 | | | |
| | Sugarcane | 52,811 | — | — | — |
| Net present worth (Rs/ha)*(without subsidy) | Banana | 2,41,753 | — | — | — |
| | Grapes | 5,40,240 | | | |
| | Sugarcane | 169896 | — | — | — |
| Benefit-cost ratio* (without subsidy) | Banana | 2.288 | — | — | — |
| | Sugarcane | 1.909 | | | |
| | Grapes | 1.767 | — | — | — |

*Source:* Computed using Narayanamoorthy 1996, 1997 and 2001

*Notes:* Banana and grapes data relate to the year 1993-94 and sugarcane data relate to the year 1998-99;
* - 15 % of discount rate is considered for computing benefit cost ratio.

state-wise potential, which reflect the true variation of land use and cropping pattern. Keeping in view the limitations of the existing estimates, we make a fresh attempt to estimate the potential area for drip and sprinkler irrigation separately covering all the major states.

Various crops that are highly suitable for drip method of irrigation are extensively cultivated in different parts of India. Micro-irrigation is not only suitable for those areas that are presently under cultivation, but it can also be operated efficiently in undulating terrain,

**Table 4.** Available estimate on potential area for drip and sprinkler irrigation in India.

(Area in mha)

| Crop | INCID(sprinkler) | TFMI (drip) | TFMI (sprinkler) |
|---|---|---|---|
| Cereals | 27.6 | — | 27.6 |
| Pulses | 4.2 | — | 7.6 |
| Oilseeds | 11.1 | 3.8 | 4.9 |
| Cotton | 2.6 | 7.0 | 8.8 |
| Vegetables | 2.5[a] | 3.6 | 6.0 |
| Spice and condiments | 1.2 | 1.4 | 2.4 |
| Flowers, medicinal and aromatic plants | — | — | 1.0 |
| Sugarcane | 3.3 | 4.3 | 4.3 |
| Fruits | — | 3.9 | 3.9 |
| Coconut, plantation crops, oil palm | — | 3.0 | 3.0 |
| Total | 42.5 | 27.0 | 69.5 |

*Sources:* INCID 1998 and GOI 2004

*Note:* a – includes fruits and vegetables.

rolling topography, hilly areas, barren lands and areas which have shallow soils (Sivanappan 1994). Since most of the potential areas are not under cultivation presently, for the purpose of the analysis, we broadly divide the total potential into two categories as ‘distant potential’ and ‘core potential’. ‘Distant potential’ refers to all those areas that are suitable for drip method of irrigation, but may not be under cultivation presently. Lands (area) that are falling under the categories of barren and unculturable lands, culturable wastelands and fallow lands can be treated as ‘distant potential’. In India, as per the land utilization data of 2000-01, about 56.28 million hectares of land is available under these categories. Unlike FIM, land-levelling and ploughing are not necessary for cultivating crops (especially horticultural crops) under DIM. Therefore, without incurring heavy expenditures on land reclamation activities, these areas could be brought under DIM cultivation in a phased manner.

However, since an irrigation source is essential for adopting micro-irrigation, we have excluded all those areas that are suitable for drip irrigation, but not currently under irrigation. We focus our estimate to the area already under irrigation. That is, only those suitable crops that are currently cultivated under irrigation is treated as potential area for drip irrigation. The important crops that are suitable for DIM are pulses, groundnut and other oilseed crops, sugarcane, fruits, vegetables, flowers, condiments and spices, cotton, etc. The state-wise area under these crops (Table 5) shows that the total potential area for drip irrigation is about 21 mha for the country as a whole, which is almost 6 million hectares less than the TFMI estimate. Of this potential, area for oilseed crops alone accounts for 27.7 %, followed by sugarcane, fruits and vegetables. As expected the potential area available from each state varies considerably, because of varied cropping pattern and availability of irrigation facilities. Among the states, Uttar Pradesh has more potential followed by Rajasthan, Gujarat, Maharashtra, Punjab and Madhya Pradesh. In fact, Uttar Pradesh, Rajasthan and Punjab together account for about 50 % of India’s total potential area for drip method of irrigation.

**Table 5.** State-wise potential for drip method of irrigation: 2000-01.

(Area in '000 ha)

| States | Pulses | S.cane | C &S | F & V | Oil seeds | Cotton | Others | Total |
|---|---|---|---|---|---|---|---|---|
| 1. AP | 21 | 360 | 233 | 328 | 423 | 192 | 127 | 1,684 (8.02) |
| 2. Assam | - | - | - | - | 2 | - | 0 | 2 (0.01) |
| 3. Bihar | 19 | 33 | 8 | 286 | 55 | - | 13.7 | 415 (1.97) |
| 4. Gujarat | 68 | 255 | 173 | 295 | 727 | 631 | 116 | 2,265 (10.78) |
| 5. Haryana | 59 | 140 | 5 | 58 | 350 | 554 | 0 | 1,166 (5.55) |
| 6. HP | 6 | 1 | 2 | 14 | 3 | @ | 0 | 26 (0.12) |
| 7. J & K | 4 | @ | 1 | 20 | 55 | @ | 1 | 81 (0.39) |
| 8. Karnataka | 80 | 417 | 160 | 200 | 500 | 73 | 72 | 1,502 (7.15) |
| 9. Kerala | - | 3 | 36 | 29 | 166 | - | 0 | 234 (1.11) |
| 10. MP | 937 | 74 | 117 | 145 | 207 | 144 | 0 | 1,624 (7.73) |
| 11. Maharashtra | 267 | 595 | 135 | 599 | 232 | 131 | 6 | 1,965(9.35) |
| 12. Orissa | 64 | 31 | 50 | 210 | 53 | - | 4 | 412(1.96) |
| 13. Punjab | 49 | 116 | 4 | 137 | 116 | 721 | 9 | 1,152(5.48) |
| 14. Rajasthan | 382 | 13 | 410 | 89 | 1,311 | 496 | 1 | 2,702(12.86) |
| 15. TN | 60 | 315 | 73 | 276 | 553 | 65 | 8 | 1,350(6.43) |
| 16. UP | 624 | 1,844 | 30 | 743 | 719 | 5 | 13 | 3,978(18.93) |
| 17. WB | - | 8 | - | - | 326 | - | 0 | 334 (1.59) |
| INDIA | 2,652 (12.62) | 4,217 (20.07) | 1,446 (6.88) | 3,508 (16.07) | 5,826 (27.73) | 3,013 (14.34) | 341 (1.65) | 21,009 (100) |

*Sources:* Computed using GOI 2003; www.agricoop.nic.in

*Notes:* S.cane- sugarcane; C&S – condiments & spices; F & V – fruits & vegetables; Figures in brackets are percentages to total; @ - below 500 hectares

The characteristics of sprinkler irrigation method are somewhat different from those of drip method of irrigation. While drip method of irrigation is highly suitable for wide spaced crops, sprinkler irrigation is mostly suitable for closely grown crops like cereals and millets, and also for horticultural crops. Experimental studies do suggest that SIM is suitable for even paddy crops. SIM also suits undulating terrain, rolling topography, hilly areas, barren lands and areas which have shallow soils (INCID 1998). But these areas are not under irrigation, so we exclude them too. The estimate presented in Table 6 shows that India's total potential for sprinkler irrigation would be about 50.2 mha. If we exclude the area under cereal crops from the estimate, the total potential would only be about 23.5 mha, which is almost equivalent to the potential area available for drip irrigation method. The total potential can go up to 74.2 mha, if paddy area is also included for estimation.

Similar to drip potential area, the potential area available for SIM also varies across the states, because of the differences in cropping pattern and irrigation availability. Our estimates show that UP state alone accounts for about 27.70 % of India's total potential, followed by

**Table 6**. State-wise potential for sprinkler irrigation: 2000-01.

(Area in '000 ha)

| | States | Cereals | Pulses | S.cane | C& S | F &V | Oil seeds | Cotton | Others | Total |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. | AP | 254 | 21 | 360 | 233 | 328 | 423 | 192 | 134 | 1,945 (3.87) |
| 2. | Assam | 1 | - | - | - | - | 2 | - | 0 | 3 (0.01) |
| 3 | Bihar | 3,417 | 19 | 33 | 8 | 286 | 55 | - | 13.7 | 3,832 (7.63) |
| 4. | Gujarat | 697 | 68 | 255 | 173 | 295 | 727 | 631 | 312 | 3,158 (6.29) |
| 5. | Haryana | 2,593 | 59 | 140 | 5 | 58 | 350 | 554 | 393 | 4,152 (8.27) |
| 6. | HP | 97 | 6 | 1 | 2 | 14 | 3 | @ | 5 | 128 (0.25) |
| 7. | J & K | 118 | 4 | @ | 1 | 20 | 55 | @ | 31 | 229 (0.46) |
| 8. | Karnataka | 677 | 80 | 417 | 160 | 200 | 500 | 73 | 77 | 2,184 (4.35) |
| 9. | Kerala | 0 | - | 3 | 36 | 29 | 166 | - | 37 | 271 (0.54) |
| 10. | MP | 2,364 | 937 | 74 | 117 | 145 | 207 | 144 | 121 | 4,109 (8.18) |
| 11. | Maharashtra | 1,287 | 267 | 595 | 135 | 599 | 232 | 131 | 6 | 3,252 (6.48) |
| 12. | Orissa | 37 | 64 | 31 | 50 | 210 | 53 | - | 4 | 449 (0.89) |
| 13. | Punjab | 3,550 | 49 | 116 | 4 | 137 | 116 | 721 | 677 | 5,370 (10.69) |
| 14. | Rajasthan | 2,801 | 382 | 13 | 410 | 89 | 1311 | 496 | 421 | 5,923 (11.79) |
| 15. | TN | 130 | 60 | 315 | 73 | 276 | 553 | 65 | 27 | 1,499 (2.98) |
| 16. | UP | 9,367 | 624 | 1,844 | 30 | 743 | 719 | 5 | 620 | 13,952 (27.78) |
| 17. | WB | 339 | - | 8 | - | - | 326 | - | 0 | 673 (1.34) |
| India | | 26,703 (53.17) | 2,652 (5.28) | 4,217 (8.40) | 1,446 (2.88) | 3,508 (6.99) | 5,826 (11.60) | 3,013 (6.00) | 2,856 (5.69) | 50,221 (100.0) |

*Source:* Same as in Table 5

*Note:* The crops mentioned in the table are identified as the suitable crops for SIM by the INCID 1998.

Rajasthan, Punjab, Haryana, MP and Bihar. The state level position can change completely, if we exclude the cereal crops from the estimate. For instance, in the case of UP state, the potential area would go down from 13.95 mha to 9.37 mha, if cereal area is excluded from the estimate. Similarly, the potential of Punjab would be only 1.82 mha, instead of 5.37 mha. We presume that the large-scale adoption of sprinkler irrigation may not take place immediately given the low canal water rates and electricity tariffs. Therefore, it is prudent to classify the potential into two as 'soft' and 'hard' potential so that policy decision can be made easily for achieving the target.

It is to be noted here that the potential area for drip and sprinkler method of irrigation is expected to change over time depending upon the land use pattern, crop pattern, irrigated area and the level of groundwater exploitation across states. The proactive policy of the state can also influence the adoption of WST significantly, as has been experienced in Maharashtra. Given the overexploitation of groundwater in different parts of the country and changes in cropping pattern, the estimated potential area for both drip and sprinkler method of irrigation might increase considerably in the future.

## Conclusion and Policy Interventions

The estimate presented in the preceding section suggests that the potential for both drip and sprinkler irrigation is very large in different states of India. Micro-irrigation reduces the cost of cultivation, weed problems, soil erosion and increases water use efficiency as well as electricity use efficiency, besides helping reduce the overexploitation of groundwater. In spite of having many economic and other advantages, the growth of area under micro-irrigation has not so far been appreciable compared to the total potential. As of now, the area under drip irrigation has extended to only 2.13 % of its potential while in the case of sprinkler irrigation the corresponding proportion is 3.30 %. Additionally most of this development has been due to the support (subsidy) from state agency. Quite a few policy and technical reasons have been identified for the slow growth and the adoption of WSTs in India. Given the vast potential benefits of micro-irrigation and fast decline of irrigation water potential in the country, a number of technical and policy interventions are required to be introduced so as to increase the adoption of micro-irrigation in India. Some specific interventions needed are presented below:

1. Sprinkler irrigation has generally been promoted through subsidy schemes and not as an on-farm water and land management strategy. In certain states (for example, Maharashtra), under subsidy scheme, no consideration is given in respect of field size, shape, topography, type and the location of water source, seasonal fluctuations, type of soil and crops to be grown. The design aspect is ignored so as to reduce the cost of the system. According to Kulkarni 2005, "in most cases the subsidy sets do not match the site specific situations of an individual farmer. As a result, the sets do not operate satisfactorily" (p.5). This can discourage the farmers not to adopt sprinkler irrigation. Therefore, the subsidy scheme needs to be modified and must take in to consideration the design aspect of the system.

2. Both drip and sprinkler irrigation are driven through the state and central government sponsored subsidy schemes. In order to earn quick profit from the subsidy programs, many companies are marketing various sub-standard components in the market. Often the sub-standard components affect the working condition of the system which creates enormous doubt in the farmer's mind about the functioning of the system. It is to be ensured that only good quality components having the certification of Bureau of Indian Standards (BIS/ISO) are supplied to the farmers. There is also a need to establish a Central Testing Facility (CTF) to deal comprehensively with the design, development and testing of all equipment, devices and machines used in sprinkler and micro-systems using state-of-the-art technology (Kulkarni 2005; GOI 2004).

3. There has been a significant development in sprinkler technology all over the world. Several variations of sprinkler irrigation system, with improved design and components are available in those countries, where it is popularly used. Efforts should be made to manufacture such improved sprinkler systems through joint ventures, with the condition that the imported components and technology would be transferred to indigenous manufacture within a period of 2 years. This would help reducing the cost of the system and increasing the adoption of micro-irrigation at a large scale. As suggested by TFMI, at least 1 % of the outlay on micro-irrigation needs to be earmarked for micro-irrigation research.

4. One of the major reasons for the slow growth of micro-irrigation in India is the high initial investment. In spite of the availability of subsidy from state agencies, the majority of the farmers are reluctant to invest in micro-irrigation system even in horticulture crops, which is highly suitable for drip irrigation. Therefore, as suggested by TFMI, there is a need to look into the technological options, of which crop geometry modification is the most important one. Instead of adopting traditional spacing, adoption of paired row planting has been found to reduce the cost of the system by 40 % in many crops including tomato, brinjal, okra, etc. Therefore, micro-irrigation system should be tailor made, i.e., planned and designed based on location specific parameters. Standard procedure provided under subsidy scheme may not always help to reduce the cost of the system.

5. It is understood from the field studies that capital cost required to install drip irrigation is relatively high. Because of this reason, considerable percentage of farmers have expressed that they are unable to adopt this technology for low- value crops. If drip system is made available at a low cost, area under drip irrigation can be increased at a faster rate. Therefore, measures need to be taken to reduce the fixed cost of drip irrigation by promoting research and development activities. By recognizing drip industry as an infrastructure industry as well as announcing tax holiday for specific time periods to all those drip set industries which produce genuine drip materials, the competition can be increased to ultimately bring down the cost of the system. Some companies have come out with low-cost drip irrigation systems, which can be adopted even by the farmers having less than one acre of land. Studies need to be carried out to find out the feasibility of low- cost drip materials including its environment feasibility using field level data.

6. The centrally sponsored scheme of drip irrigation does not provide a subsidy for the sugarcane crop. The logic behind this is not clearly known. Since it is an important and also a heavy water-consuming crop, this restriction should be removed to increase the drip irrigated area at a faster rate. This would also ultimately help to reduce the water crisis faced by various states to some extent.

7. The rate of subsidy provided through government schemes is fixed uniformly for both water-intensive as well as less water-intensive crops. This needs to be restructured. Special subsidy program may be introduced for water-intensive crops like sugarcane, banana, vegetables, etc. Differential subsidy rates can be fixed based on the types of crops and the rate of consumption of water. Uniform level of subsidy schemes currently followed for water-scarce and water-abundant areas need to be changed and higher subsidy should be provided for those regions where the scarcity of water is acute and exploitation of groundwater is very high as well.

8. Sugar industries always try to increase the area under sugarcane to increase their capacity utilization in almost all the states in India. They are least bothered about the method of sugarcane cultivation. Since sugar industries have close contact with sugarcane cultivators, some kind of target may be fixed for each sugar industry to bring cultivation of sugarcane under DIM. Apart from the saving of water, this would also help achieve cultivation of sugarcane in a sustainable manner. Despite irrigation water shortage in many states, not only does the area under sugarcane continue to

grow at a relatively faster rate, but it is cultivated predominantly under flood method of irrigation. This puts additional pressure on our limited water resources.

9. Drip set manufacturers should be asked to involve intensively in promoting micro-irrigation by organizing frequent demonstrations at farmers' fields. Since the use of micro-irrigation is still in the take-off stage in India, an active role of the manufacturers is essential in promoting drip irrigation as well as developing confidence among the farmers about the usefulness of this new technology. The micro-system manufacturers should be involved in providing advice on agronomic packages to the farmers so as to encourage the adoption of WSTs on a large scale.

10. For a speedy growth of micro-irrigation, a special package scheme can be introduced where priority can be given to providing bank loans for digging wells and electricity connection (pump-set) for those farmers who are ready to adopt micro-irrigation for cultivating any crop.

11. Groundwater is the only source of water being used for drip method of irrigation in India. Unlike other countries, water from surface sources (dams, reservoirs, etc.) is not used for drip method of irrigation. Since water use efficiency under surface sources is very low owing to heavy losses through conveyance and distribution, farmers should be encouraged to use water from surface sources for drip method of irrigation. This can be done by allocating a certain proportion of water from each irrigation projects only for the use of micro-irrigation.

12. One of the important reasons for the low spread of this technology even in the water-scarce area is the availability of highly subsidized canal water as well as electricity for irrigation pump sets. Appropriate pricing policies on these two inputs may also encourage the farmers to adopt this technology.

To conclude, the potential area for MI presented above is estimated based on the present cropping pattern and irrigation coverage of different states in India. One may not be able to argue that this potential area would be the same even after 10 or 20 years because of changes in the parameters that determine MI potential. The potential area available for MI is governed by factors such as cropping pattern, irrigation coverage, groundwater scarcity, price of canal water, price of electricity as well as its supply (in hours) for agriculture, technology development in MI, proactive policy (subsidy and other incentives) of the state and central governments. In case farmers shift the cropping pattern more in favour of horticultural crops because of their high profitability, the potential area for DIM might increase significantly in the future. Similarly, if the depletion in groundwater in different regions aggravates further, it might also encourage the farmers to shift the irrigation method from flood to MI methods. What will be the potential area for DIM and SIM if cropping pattern changes drastically in favor of high-value horticultural crops in another 10 years? Does the potential for MI change if one estimates it under different scenarios of groundwater depletion? Will the potential area for MI change if full cost pricing is introduced in canal water and electricity supplied for irrigation pump sets? One may be able to find some interesting results if comprehensive analysis is carried out covering the issues flagged here. In any case, the potential area for MI is not going to be static.

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