Microirrigation Technologies for Water Conservation and Sustainable Crop Production

V. Praveen Rao* **and V. Anitha**

Professor Jayashankar Telangana State Agricultural University, Rajendranagar, Hyderabad, Telangana (500 030), India

Corresponding Author

V. Praveen Rao
e-mail: v.prao@yahoo.com

Article History

Article ID: IJEP50
Received in 5th August, 2015
Received in revised form 28th November, 2015
Accepted in final form 15th December, 2015

Abstract

Microirrigation refers to the slow application of water on, above, or below the soil by surface drip, subsurface drip, bubbler, and microsprinkler systems. Water is applied as discrete or continuous drips, tiny streams, or miniature spray through emitters or applicators placed along a water delivery line adjacent to the plant row. Microirrigation encompasses drip or trickle (both surface and subsurface), microsprinklers (spinners and rotators), micro-jets (static and vibrating), micro-sprayers, bubblers. Microirrigation is now widely recognized as one of the most efficient methods of watering crops all over the world and it represents a definite advancement in irrigation technology. The Working Group on Microirrigation of the International Commission on Irrigation and Drainage (ICID) has conducted surveys on the extent of microirrigation periodically since 1981. These surveys, summarized by, indicate that area under microirrigation grew slowly but steadily and it was about 6.2 mha in 2006. The top four countries in microirrigated areas are – India, China, the USA and Spain accounting for about 66.3% of the total microirrigated area of the world. In some countries such as Israel where water availability limits crop production, microirrigation commands about 75% of the total irrigated area. Enough empirical evidence is available from different parts of the country to suggest that drip technology saves water in comparison to surface method of irrigation from 18.7 to 47.7% in orchards and fruits, 2.1 to 42.9% in field crops, 11.9 to 38% in vegetable crops, 14.3 to 51.3% in root, bulb and tuber crops, 12 to 56% in plantation crops, 36.7 to 46.7% in spice crops and 41.4 % in flowers in a properly designed and managed drip irrigation system.

Keywords: **D**rip irrigation, microirrigation, sustainable crop production, water conservation

1. Background

Microirrigation refers to the slow application of water on, above, or below the soil by surface drip, subsurface drip, bubbler, and microsprinkler systems. Water is applied as discrete or continuous drips, tiny streams, or miniature spray through emitters or applicators placed along a water delivery line adjacent to the plant row (ASAE, 2001). Microirrigation encompasses drip or trickle (both surface and subsurface), microsprinklers (spinners and rotators), micro-jets (static and vibrating), micro-sprayers, bubblers. Microirrigation is now widely recognized as one of the most efficient methods of watering crops all over the world and it represents a definite advancement in irrigation technology. Microirrigation in the form of surface drip was first used in Arava and Negev deserts of Israel, where adverse conditions of climate, very sandy alkaline soils, and saline water had produced poor results on crops grown with conventional irrigation methods. Preliminary field trials using surface drip irrigation for irrigating crops in these conditions resulted in superior plant growth, greater yields, and significant savings in water relative to conventional irrigation techniques. The publicity surrounding these first reports not only led to grower acceptance of drip irrigation in Israel but also stimulated considerable interest around the world in drip irrigation techniques as a possible substitute where conventional irrigation practices were not successful. Thus its wide-scale adoption commenced in 1970s in countries as diverse as Australia, Israel, Mexico, New Zealand, South Africa, and USA to irrigate vegetables, orchards and its coverage was reported as 56,000 ha.

The Working Group on Microirrigation of the International Commission on Irrigation and Drainage (ICID) has conducted surveys on the extent of microirrigation periodically since 1981. These surveys, summarized by (Reinders, 2000), indicate that area under microirrigation grew slowly but steadily and it was about 6.2 mha in 2006 (Figure 1). In the last worldwide survey of micro irrigation (2010) carried out by ICID, data of 42 countries was reported and currently, some 9.95 Mha are under microirrigated crops world over. The top four countries in microirrigated areas are –India, China, the USA and Spain accounting for about 66.3% of the total microirrigated area of the world. In some countries such as Israel where water availability limits crop production, microirrigation commands about 75% of the total irrigated area.

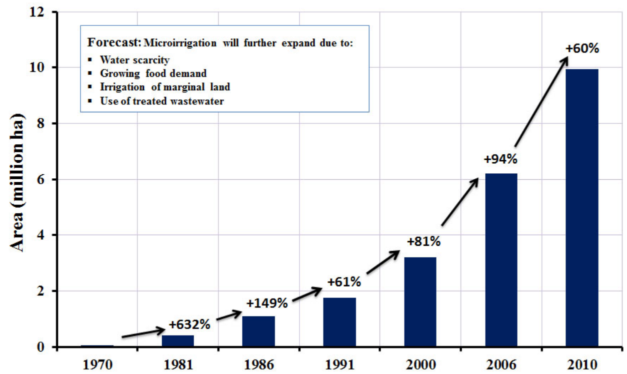

Figure 1: Global microirrigation expansion (1970 – 2010)

(Bucks, 1993) indicated that the main reasons for choosing microirrigation were: (1) higher water and labor costs (2) limited water (3) water supply was saline (although periodic leaching was still required); (4) the use of other irrigation methods was difficult (example, hillside orchards); (5) landscaping or greenhouse irrigation was required; and (6) fertigation & chemigation was possible. Further, in 2006 the key findings and recommendations of the 7th International Micro Irrigation Congress held at Kuala Lumpur indicated that the microirrigation technologies owing to their capability to apply water efficiently, low labour and energy requirement, and increase in quantity and quality of crop yield or produce, economics, with concurrent increases in fertilizer use efficiency have made a breakthrough in many countries around the globe. Although the area under microirrigation has expanded 177-fold over the last four and half decades, it still represents only 3.46 percent of the world's total irrigated area (287 Mha). Likewise the area under microirrigation in India though expanded 1380-fold over the last three decades, it still represents only 3.07% of the country's total net irrigated area (65 Mha). Further, today there are only 5-states viz., Maharashtra, erstwhile united Andhra Pradesh, Karnataka, Gujarat and Tamil Nadu accounting for about 90% of the total microirrigated area of 2.0 million ha in the country (Figure 2).

According to Microirrigation Technology Mission Report about 80 crops, both narrow and widely spaced crops can be raised under drip irrigation in India with an estimated theoretical ultimate drip irrigation potential of 27 Mha. The principal determinants of microirrigation adoption include access to groundwater, cropping pattern, availability of cash, and level of education, the social status and poverty status of the farmer **(**Postal et al., 2001**).**

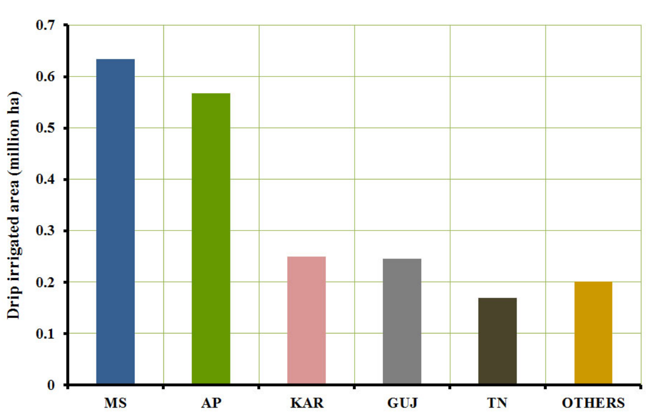

Figure 2: Microirrigation area in different states of India

2. Microirrigation–Drivers for Adoption

A survey of literature on the impacts of microirrigation technologies in India indicates that they are usually promoted primarily for one or more of the following objectives

1. As a means to save water in irrigated agriculture and avert the water scarcity crises in arid and semi-arid regions and groundwater irrigated commands,

2. To enhance crop and water productivity and crop quality in irrigated agriculture

3. To safeguard crops against crop loss or yield reduction due to dry spell or early withdrawal of rain in humid regions

4. As a means to overcome labour shortages and avert productivity decline

5. Power saving motives in case of low power supply, well ownership, depth of wells and horse power of the pumps

6. As a strategy to use marginal quality waters viz., saline water or brackish water, effluents from wastewater treatment plants, effluents from sugar mills etc

7. For successful cultivation of fruit crops and Silviculture plantations on marginal and gravel soils

8. To obtain uniform nursery seedlings or saplings with high percentage of success rates

9. As a strategy to increase income and reduce poverty among the rural poor and

10. To enhance the food and nutritional security of rural households.

3. Principle Crops Utilizing Micro Irrigation

Worldwide experience during the last four decades has shown that currently the bulk of the available MI technologies are employed in fruit and orchard crops, tuber and bulb crops, vegetables, spice crops like chilli, ginger and turmeric; plantation crops like oil palm, coconut, coffee and tea; commercial field crops like cotton and sugarcane; protected agriculture (crops raised under greenhouse, shade nets, walking and shallow tunnels) and other applications (use of saline water, treated wastewater effluents etc.). But, its adoption in production of major agronomic field or food row crops viz., rice, wheat, oil seeds and pulses, in many countries including India has been very small relative to conventional irrigation systems. Although there are some experimental evidences of use of drip irrigation in food crops viz., cereals, oilseeds and pulses in India, Australia, the USA, China etc., but its application is yet to spread on farmers' fields. An IWMI study in Gujarat and Maharashtra indicated that the higher the share of cereals and pulses in the cropping pattern the lower the probability of adopting MI technologies. This implies that farmers growing staple food crops such as cereals and pulses are currently excluded from the benefits of innovations in MI technologies. In the long run, however, this scenario may be reversed due to two possible reasons: (1) the micro irrigation engineers may innovate to develop cost effective systems for the crops which are currently not suited to micro irrigation applications, and (2) the farmers may shift their cropping pattern to benefit from innovations in the MI systems. The latter response will have substantial impacts on the water-resources economy of a watershed or basic.

4. Yield and Water Productivity Gains

Enough empirical evidence is available from different parts of the country to suggest that drip technology saves water in comparison to surface method of irrigation from 18.7 to 47.7% in orchards & fruits, 2.1 to 42.9% in field crops, 11.9 to 38% in vegetable crops, 14.3 to 51.3% in root, bulb & tuber crops, 12 to 56% in plantation crops, 36.7 to 46.7% in spice crops and 41.4 % in flowers in a properly designed and managed drip irrigation system (Table 1). Drip irrigation induced water savings result from irrigation of a smaller portion of soil volume, decreased surface evaporation, reduced irrigation runoff from the field (the dry soil between rows could also store more precipitation) and controlled de-percolation losses below the crop root zone **(**Aljibury, 1974; Davis, 1975; Shoji, 1977)**.** Wu and Gitlin (1981) concluded that an application efficiency of 90% could easily be achieved for drip irrigation as compared to 60 – 80% for sprinkler and 50–60% for surface irrigation. Water uptake by weeds (Lemon, 1956) is also minimized by not wetting the entire soil surface (partial wetting of the root zone) between rows or trees, especially on young trees or row crops before the closure of the canopy. Sprinkler irrigation is subject to the water loss by wind drift, increases evaporation or poor application uniformity especially with strong winds (Seginer, 1969).

According to data available from research trials and farmer's fields, yield and water productivity gain due to use of drip irrigation systems (surface & subsurface drip system) was in the range of 36.7 to 313.7% for different crops (Table 1). While increasing the water savings and productivity of crops, drip irrigation also delivers many other potential economic and social benefits to the society–increased farm profits; uses less labour, reduction in electricity (44–67%), fertilizer and labour (29–60%) costs; poverty reduction among the rural poor; food and nutritional security of rural households; addresses environmental concerns, etc. (Narayanamoorthy, 2003 and 2005; Polak et al., 1997; Palanisami et al., 2011). The income and poverty reduction effects of drip irrigation technologies are attained through substantial increases in farm income due to higher crop yields, better output quality,

Table 1: Yield and Water Productivity Gains from Shifting to Drip from Conventional Surface Irrigation

Crop	Yield gain (%)	Reduction in Water use (%)	Water productivity gain (%)
Orchard and fruit crops			
Banana	52.1	44.8	176.7
Table grapes	23.1	47.7	135.6
Kinnow	25.7	34.9	93.7
Papaya	50.0	40.0	150.2
Watermelon	87.5	36.3	194.7
Pomegranate	94.6	18.7	139.5
Mango	42.0	33.0	114.0
Field crops			
Castor	67.8	10.3	87.7
Cotton	40.9	42.9	147.0
Mulberry	112.2	41.8	265.0
Sugarcane	106.8	20.7	161.5
Sunflower	32.9	2.1	36.7
Cassava	92.2	21.5	145.1
Vegetable crops			
Broccoli	39.2	14.3	62.5
Lady's Finger	33.3	38.0	115.4
Tomatoes	52.5	37.2	143.3
Bell pepper	28.2	26.1	73.6
Pumpkin	15.6	22.5	49.2
Cauliflower	67.8	31.7	145.8
Cabbage	25.0	36.2	96.0
Bottle gourd	46.8	11.9	66.8
Roots, bulb & tuber crops			
Onion	98.3	14.3	131.5
Potato	38.6	39.8	130.5
Radish	53.1	51.3	215.1
Sugarbeet	17.2	25.0	56.4
Plantation crops			
Coconut	70.0	56.0	289.0
Oil palm	21.0	38.0	86.0
Tea	52.0	12.0	72.0
Spice crops			
Chillies	100.0	46.7	276.7
Turmeric	86.0	36.7	194.6
Flowers			
Chrysanthemum	140.2	41.4	313.7

early crop maturity, realization of higher unit output prices, and reduced cost of cultivation—particularly for operations like irrigation and weeding. Drip irrigation technologies enable the production and consumption of vegetables, particularly leafy vegetables, which are usually missing in the traditional staple diets of many cultures addressing the malnutrition problem. In addition to these direct benefits, adoption of drip technology generates both positive and negative externalities (Dhawan, 2000).

The positive externalities include reduction in well failure rates, reduction in the cost of deepening existing wells and cost of drilling new wells, and increased availability of irrigation water (Kumar et al., 2008). The negative externalities include reduction in labour employment due to shifts in cropping patterns (Dhawan, 2002). Drip irrigation technology besides conserving water maximizes the synergistic interactions of improved seeds, water and fertilizer ensuring the congruence of sustainability, productivity, profitability and equity.

5. Fertigation of Crops

Introduction of simultaneous micro irrigation and fertilization (fertigation) opened up new possibilities for controlling water and nutrient supplies to crops and maintaining the desired concentration and distribution of ions and water in the soil (Bar-Yosef, 1999). Because drip systems have a high degree of uniformity when designed properly and can apply small amounts of irrigation frequently, and they provide excellent opportunities to better manage fertilizer nutrients. Fertigation transports fertilizers and water to the rhizosphere of crops directly, which reduces the contact of nutrients and water with soil, and saves water and fertilizer greatly over broadcast applications (Haynes and Swift, 1987). Many growers with micro irrigation systems apply daily amounts of fertilizer. Fertigation is now a regular and widely accepted practice for fertilization of agricultural and horticultural crops (Bar Yosef, 1999; Praveen Rao, 2010). Effective fertigation requires calculation of nutrient requirements based on plant requirements and soil nutrients, selection of the most effective formulations, preparation of solutions for injection, and scheduling injections to ensure that essential nutrients are available as needed (Granberry et al., 2001). Fertilizer application rates depend on crop, soil, and time (Haynes, 1985). Thus, individual growers and agronomists often use trial and error approach to develop and standardize fertilization schemes under field conditions that are specifically tailored to elicit the desired crop response, yield, and quality.The fertilization application rate is usually split into parts and applied according to the biological curve of crop nutrient assimilation during the vegetation and reproductive period (Burt, 2003). Fertilizer placement (band placement; on-surface or subsurface fertigation), timing (crop developmental stage), fertigation and irrigation frequency (daily, weekely, monthly, etc) and nutrient rate all influence yield, water and nutrient use efficiency (Bar-Yosef, 1999; Li et al., 2004). Fertilizers for fertigation systems are selected based on plant response, solubility, cost, effect on soil pH, formulation, and potential for reaction with other chemicals within the distribution system. Commonly used water soluble fertilizers for fertigation through micro irrigation systems are listed in (Figure 3).

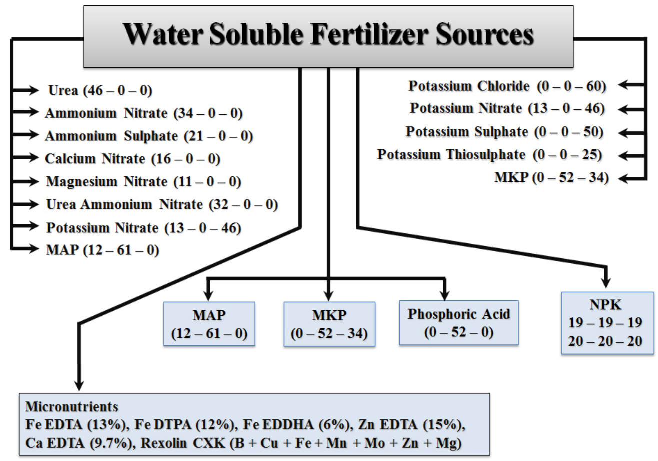

Figure 3: Water soluble fertilizers commonly used in micro irrigation systems

Fertigation responses of orchard, fruit, vegetable and field row crops are well documented in the technical and popular literature (Bar-Yosef, 1999; Dasberg and Or, 1999). In addition various experiments registered significant fertilizer savings (20 – 60%) through drip fertigation (Table 2).

Table 2: Fertilizer savings in drip irrigated crops

Sl. No.	Crop	Fertilizer saving	Reference
1.	Cotton	20–30%	Bharambe et al. (1997)
2.	Castor	25–60%	Patel et al. (2006)
3.	Chickpea	25%	Deolanker and Pandit (1998)
4.	Sugarcane	25–50%	Viashnava et al. (2002)
5.	Banana	25–35%	Kumar & Pandey (2008)
6.	Apple	40%	Hipps (1992)
7.	Mango	25%	Panwar et al. (2007)
8.	Onion	20–40%	Patel & Rajput (2003)
9.	Tomato	20–40%	Patel & Rajput (2003)
10.	Broccoli	20–40%	Patel & Rajput (2003)
11.	Lady's finger	20–40%	Patel & Rajput (2003)
12.	Cauliflower	25%	Kadam et al. (2006)
13.	Chilli	25%	Deolankar and Firake (1999)

6. Protected Cultivation

Micro irrigation systems are increasingly used in different types of greenhouses (i.e. semi climate controlled and naturally ventilated), walk-in tunnels, low plastic tunnels, insect proof net houses and shade net houses for cultivation of different vegetable crops and flowers. It offers distinct advantages of quality, productivity and favourable market price to the growers over open field cultivation. Experiments conducted under Indo-Israeli Project at IARI, New Delhi indicated that 200-210 tons ha^{-1} of tomatoes and 80–90 tons ha^{-1} of cherry tomatoes were harvested over a period of 10–11 months. Similarly, several exotic and indigenous varieties of sweet pepper registered an yield of 40–50 tons ha^{-1}. Naturally ventilated greenhouses along with drip irrigation enabled year-round cultivation of parthenogenic slicing cucumbers with an average very high quality seedless slicing cucumbers fruit yield of 100–110 t ha^{-1} year^{-1}. Likewise in summer squash (var. Australian Green) 70 t ha^{-1} fruit yield was recorded with a cost-benefit ratio varying between of 1:2.96 and 1:4.42 under plastic low tunnels with drip irrigation. Whereas, in muskmelon 22 t ha^{-1} of fruit yield was recorded with a cost benefit ratio of 1:3.86. Protected cultivation provides many fold advantages over open field vegetable cultivation. This technology is highly productive, amenable to automation, conserves water, fertilizer and land. It is also eco-friendly and does not require much sophistication. Increased productivity and off-season production capability under protected conditions along with micro irrigation and automation favour its early adoption in peri-urban areas of northern plains, central and southern parts of the country and hilly areas of India.

7. Drip Irrigation with Marginal Quality Saline Waters

Water placement and minimal evaporation loss are key elements to saline irrigation. The advantage a drip system has over many others is the placement of water near or in the root zone. Salts are pushed outward from the root zone due to micro-leaching effect, particularly in a subsurface drip irrigation system. The amount of water required to leach salts will be limited to the amount required to move salt out of that root zone not the field. This reduces the amount of salts applied to a field and subsequently, a catchment. Daily drip irrigation frequency with brackish water was found to result in lower average salinity profiles, compared to a 3–4 day irrigation frequency. Under high evaporative conditions in the Negev highlands of Israel during summer an irrigation frequency of five times a day (pulse irrigation) in tomatoes with brackish water leached salts from the root zone relieving salt stress, with a resulting increase in yield. Further when using low quality water, drip irrigation has several advantages over other irrigation methods because it does not wet the foliage, and because of its high application frequency, concentrations of salts in the rooting zone remain manageable. Studies on subsurface drip irrigation and furrow irrigation in the presence of shallow saline ground water indicated that yield of tomato were greater under drip irrigation than under furrow irrigation.

8. Technical and Economic Efficiency

The technical efficiency as indicated by marginal physical product (MPP) i.e., extra yield advantage that a farmer derives when shifting from the conventional surface irrigation to a micro irrigation practice (Table 1) alone does not guarantee economic efficiency. A farmer may well operate in the technically efficient region of the production function but may still be judged as economically inefficient, based on considerations of input output price relations. Thus, to evaluate the economic efficiency of the different micro irrigation technologies we need to consider the input-output price relationships. In the present case, this was achieved through calculating net present value (NPV) and payback period (Figure 5). From the results of the economic efficiency analyses for several crops on hand drip irrigation technologies were economically efficient and the farmers can recover their initial investment capital within 1 to 2 years for annual crops and 4 to 8 years for fruit crops without subsidy benefit. Subsidies may further increase the profitability of investments in drip irrigation technologies. However, the magnitude of economic gains from investments in drip irrigation technologies depends on the type of crop and drip product used.

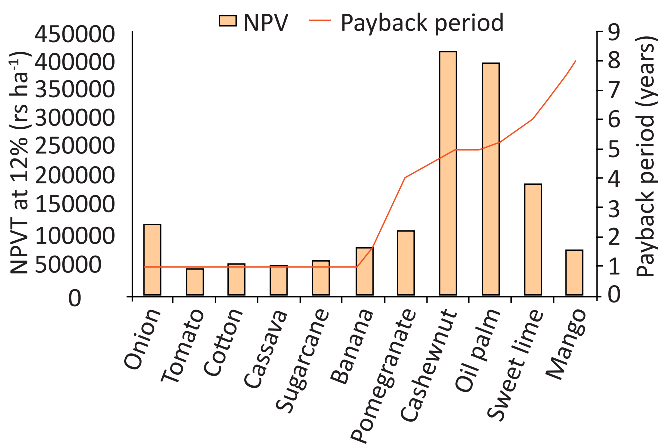

Figure 5: Economic efficiency parameters for drip irrigated crops

9. Social and Poverty Status Vs Adoption of MI Technologies

Despite the technical transformation of micro irrigation products to make them pro-poor, well-to do farmers still have a significantly higher probability of adopting micro irrigation technologies in several states. Therefore, reducing the cost alone through substantial subsidies is not enough to improve the poverty outreach of MI technologies. Three factors limit poor farmer's access to MI technologies.

- The available subsidized MI systems are suited to crops that are not popular among poor farmers who tend to allot a significant proportion of their area to staple food crops such as cereals and pulses.
- Their socioeconomic attributes (e.g., low level of education, being a member of a low-caste group, low poverty status, etc.) limit their access to information, ultimately hindering their access to MI technologies.

• Limited access to resources, specifically to groundwater, quantitatively and qualitatively, hinders poor farmers from successfully adopting MI technologies.

10. Summary and Future Thrust Areas

Few people question that adjustments in irrigated agriculture will be required in the future. However, the scope of dependence on an irrigated agriculture base requires that economical and technologically sound solutions be developed. Irrigation not only helps provide an economical and stable food supply for the nation but also helps to maintain prosperous and sustainable producers and rural communities. A compelling need exists for solutions that can help maintain higher levels of irrigation sustainability where water supplies can be replenished. Most water planners and resource managers recognize that that it will take many tools working together to help avoid the significant disruption in the economies and societies grown accustomed to widespread irrigation use. Microirrigation is just one of the many irrigation and water management technology tools, but it is a tool that has several advantages. Microirrigation can reduce the waste of water to a negligible amount and the transport of contaminants to surface water and groundwater. Irrigation events can be fine-tuned to spoon feed water and nutrients just in time to avoid plant stress. It can optimize crop production (maximize economic yield for each unit of water) and in many cases increase the quality of agricultural products.

Some scientists, water planners, and resource managers have been disappointed with the rate of adoption in microirrigation. The microirrigated land area in India varies on an annual basis, but during the last 10 years has hovered in the range of 2 to 3% of the total irrigated area. It is recognized that some crops and locations are not physically or economically suitable for microirrigation, but this is probably an exception rather than a common situation. Further efforts are justified to reduce the impediments to more widespread adoption. To increase the adoption rate of appropriate microirrigation technologies, it will be necessary to assess and improve the decision criteria utilized in the adoption process and it will be necessary to improve technology transfer. The future thrust areas therefore include the following:

Evaluate and refine microirrigation management strategies for site specific conditions (crops, soils, water quality and availability, climate and irrigation system characteristics) to promote water conservation and optimal crop production.

Improve, modify, and evaluate microirrigation system design and components for water conservation and optimal crop production.

Assess and develop decision criteria for adoption of microirrigation technologies.

Promote appropriate microirrigation technologies through formal and informal educational activities.

11. Conclusion

Microirrigation is just one of the many irrigation and water management technology tools, but it is a tool that has several advantages. Microirrigation can reduce the waste of water to a negligible amount and the transport of contaminants to surface water and groundwater. Irrigation events can be fine-tuned to spoon feed water and nutrients just in time to avoid plant stress. It can optimize crop production (maximize economic yield for each unit of water) and in many cases increase the quality of agricultural products.

12. References

Aljibury, F.K., 1974. Water use in drip irrigation. Proceedings of International Drip Irrigation Congress, 341–350.

ASAE., 2001. ASAE Standard S526.2 JAN01, Soil and water terminology. American Society of Agricultural Engineers, St. Joseph, Michigan, 21.

Bar-Yosef, B., 1999. Advances in fertigation. Advances in Agronomy 65, 1–77.

Bucks, D.A., 1993. Microirrigation worldwide usage report. Pp. 11 – 30. In.: Proceedings of workshop on Microirrigation worldwide, The Hague, The Netherlands.

Burt, C.M., 2003. Chemigation and fertigation basics for California. Available from http://www.itrc.org./chemigation/basics.pdf, 21.

Dasberg, S., Or, D., 1999. Drip irrigation. Springer-Verlag Berlin, Germany, 162.

Davis, S., 1975. Drip irrigation. In "Sprinkler irrigation easily automated". Journal of Irrigation and Drainage Division of American Society of Civil Engineers 96, 47–51.

Dhawan, B.D., 2000. Drip Irrigation: Evaluating Returns. Economic and Political Weekly 42, 3775–3780.

Dhawan, B.D., 2002. Technological change in irrigated agriculture: A study of water saving methods. Commonwealth Publishers, New Delhi, India.

Granberry, D.M., Harrison, K.A., Kelley, W.T., 2001. Drip Chemigation: Injecting Fertilizer, Acid and Chlorine. University of Georgia, College of Agriculture and Environmental Science, Cooperative Extension Service, Bulletin 1130, 13.

Haynes, R.J., 1985. Principles of fertilizer use for trickle irrigated crops. Fertilizer Research 6, 235–255.

Haynes, R.J., Swift, R.S., 1987. Effect of trickle fertigation with three forms of nitrogen on soil pH, levels of extractable nutrients below the emitter and plant growth. Plant and Soil 102, 211–221.

Kumar, M.D., Sharma, B., Singh, O.P., 2008. Water Saving and Yield Enhancing Micro Irrigation Technologies in India: When and where can they become best bet technologies? International Water Management Institute. Hyderabad, India.

Lemon, E.R., 1956. The potentialities for decreasing soil moisture evaporation loss. Soil Science Society of America Proceedings 20, 120–125.

Li, J., Zhang, J., Rao, M., 2004. Wetting patterns and nitrogen distributions as affected by fertigation strategies from a surface point source. Agricultural Water Management 67, 89–104.

Narayanamoorthy, A., 2003. "Averting water crisis by drip method of irrigation: A study of two water-intensive crops". Indian Journal of Agriculture Ecology 58, 427–437.

Narayanamoorthy, A., 2005. Efficiency of irrigation: A Case of drip irrigation. Occasional Paper, 45,

Department of Economic Analysis and Research, National Bank for Agriculture and Rural Development, Mumbai, India.

Palanisami, K., Kadiri, M., Kakumanu, K.R., Raman, S., 2011. Spread and Economics of microirrigation in India: Evidence from Nine States. Economic and Political Weekly 46(26, 27), 81–87.

Polak, P., Nanes, B., Adhikari, D., 1997. A low cost drip irrigation system for small farmers in developing countries. Journal of American Water Resources Association 33, 119 – 124.

Postal, S., Polak, P., Gonzales, F., Keller, J., 2001. Drip irrigation for small farmers: A new initiative to alleviate hunger and poverty. Water International 26, 3–13.

Praveen Rao, V., 2010. Water soluble fertilizers and fertigation schedules for various horticultural and field crops (Revised). IFFCO, Regional Office, Hyderabad, India.

Reinders, F.B., 2000. Micro irrigation: A world overview. In: Proc. Sixth International Microirrigation Congress, October 22–27, 2000, Cape Town, South Africa. Paper No. P9.5., 4.

Seginer, I., 1969. Wind variation and sprinkler water distribution. Journal of Irrigation and Drainage Division ASCE 95, 261–274.

Shoji, K., 1977. Drip irrigation. Scientific American 237, 62–68.

Wu, I.P., Gitlin, H.M., 1981. Preliminary concept of a drip irrigation net work design. Transactions of ASAE 24, 330–334.