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Progress and difficulties with micro-irrigation

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Abstract
As global concerns regarding the scarcity of water and the need for food security continue to intensify, there will be an increasing demand for micro-irrigation to fulfil the growing requirements of food production. Micro-irrigation presents numerous advantages when compared to conventional irrigation methods. These advantages encompass the precise application of limited water amounts directly to the root zone of crops, the integration of fertigation, a decrease in weed and pest issues, and reduced capital and operational expenses. Over the past few decades, the adoption of micro-irrigation has expanded significantly. This expansion can be attributed mainly to cost reductions, enhancements in filtration and emitter technology, and the growing trust of growers in this technology. Ongoing research breakthroughs and technological enhancements have expanded the applicability of micro-irrigation to a wider range of uses, crop systems, and water quality conditions. The cost and availability of water also play pivotal roles in driving this shift. Promising developments in research, such as nano- and biofiltration techniques, soil moisture sensors, and precision irrigation, hold great potential for advancing micro-irrigation further. Nonetheless, several technological challenges remain, especially in the context of non-row or non-orchard crops and in regions where water quality is significantly compromised. Addressing these challenges necessitates innovation in these areas and the dissemination of this technology to small-scale farmers in water-scarce regions who have traditionally relied on surface irrigation.

Keywords: Micro-irrigation, drip irrigation, water use efficiency

Introduction

Since it is the world's largest user of fresh water, the irrigation sector is under pressure to improve its efficiency. This is compounded as water resources become scarcer as a result of climate change, and as competition for water increases from other economic and environmental purposes. As a result, demand for more efficient water applications is increasing. Micro-irrigation, which is the precise application of water at low pressure on or below the soil surface using small devices that spray, mist, sprinkle, or drip water, is becoming more popular (Hla and Scherer, 2003) [7]. Micro-irrigation previously required a large capital investment and was thus largely utilised for high-value commercial crops such as vegetables and fruit trees, and was rarely used for lower-value staple crops (Brouwer *et al*. 1988) [2].

Increased sales and technological advancements have resulted in wider global usage of micro-irrigation in recent decades. Drip irrigation is a popular type of micro-irrigation; Table I demonstrates the global expansion of drip irrigation from its inception in the 1970s.

Table II compares sprinkler irrigation and micro-irrigation areas by country, as well as their fraction of total irrigated area. In some nations, such as Spain, Korea, Israel, Poland, and Chile, drip irrigation is used more than sprinkler irrigation (Table II). It is also worth noting that India's drip irrigated area is growing and is not far behind its sprinkler irrigated area (ICID, 2011). In underdeveloped nations, several government and non-governmental organisations are actively promoting micro-irrigation (Varma *et al*. 2006) [19].

The high-value horticultural, ornamental, and landscape industries have embraced micro-irrigation and continue to be its most avid users. Drip irrigation has allowed small-scale cash crop growers to increase their output. This is especially visible in the case of vegetable cultivation in peri-urban areas of various African and Asian countries. More innovation is needed, however, to expand the use of drip irrigation for non-orchard crops including rice, wheat, and maize. To considerably expand the area covered by micro-irrigation, these technological advancements must include lower capital costs and the ability to irrigate with lower quality water.

Table 1: Worldwide growth in drip irrigation (Postel *et al*. 2001) [16]

Year	Global acreage under drip irrigation (Million ha)
1970s	0.056
1991	1.6
2001	≈2.8

Advantages and Benefits

Micro-irrigation maintains a continual supply of water in the crop root zone and has been shown to boost crop output and water use efficiency over traditional irrigation methods. Micro-irrigation systems provide extensive control over water applications. These systems are also very cost effective because they consume a little amount of water at a low pressure, resulting in lower energy expenditures (Varma *et al*. 2006) [19]. There is no percolation to groundwater and no surface runoff with micro-irrigation. Furthermore, due of the smaller wetted area, less water evaporates. Micro-irrigation is increasingly being employed as a solution to alleviate water scarcity and poverty due to its high-water consumption efficiency. Researchers such as Shah (2011) [17] have highlighted the water savings and yield increases that micro-irrigation provides (Table II). Farm productivity (Crop yield and output) is raised, as is farmer income and food security. Labour costs are minimised as harvests begin earlier. Crop quality has also improved with drip irrigation (Madramootoo and Rigby 1991) [13].

Micro-irrigation systems are generally simple to install and manage, and they can be used for a wide range of orchard and row crops, including fruit and vegetables. Because system components, such as pressure regulating valves and pressure compensating emitters, allow for consistent water distribution and application rate, land levelling is not required. The introduction of fertiliser injectors that can be linked to micro-irrigation systems to enable for fertigation, hence increasing crop nutrient management, has been a significant innovation. Water and fertiliser can be applied in reasonable amounts throughout the growing season to fit crop requirements. Furthermore, because of the lower wetted area and drier soil surface, insect and weed invasion, as well as other plant diseases, occur less frequently. The farmer saves money by reducing the amount of manpower required to safeguard crops and by minimising pesticide/herbicide use (Varma *et al*. 2006) [19].

Major Advances

Major advances have taken place in micro-irrigation technology, resulting in increased adoption and a growing number of advantages. In addition, innovations allow for a more diverse set of applications. Clogging and inefficient water filtration have traditionally been major issues when employing micro-irrigation. The invention of functional and cost-effective sand and screen filtration devices has helped to overcome this issue, and has ultimately resulted in an expanded use of micro-irrigation in areas with low-quality water.

Table 2: Areas of sprinkler and micro-irrigation for selected countries (ICID, 2011)

Country	Total irrigated area (million ha)	Sprinkler irrigation		Micro-irrigation	
		Area (ha)	% of total irrigated area	Area (ha)	% of total irrigated area
USA	24.70	12300000	50.0	1640000	6.6
India	60.90	3040000	5.0	1900000	3.1
China	59.30	2930000	4.9	1670000	2.8
Russia	4.50	3500000	77.8	20000	0.4
Brazil	4.45	2410000	54.2	328000	7.4
Spain	3.41	733000	21.5	1630000	47.8
Italy	2.67	981000	36.8	571000	21.4
France	2.90	1380000	47.6	103000	3.6
South Africa	1.67	920000	55.1	365000	21.9
Saudi Arabia	1.62	716000	44.2	198000	12.2
Iran	8.70	460000	5.3	270000	3.1
Australia	2.55	524000	20.6	191000	7.5
Canada	0.87	683000	78.5	6030	0.7
Mexico	6.20	400000	6.5	200000	3.2
Korea	1.01	200000	19.8	400000	39.6
Israel	0.23	60000	26.0	170000	73.6
Morocco	1.65	190000	11.5	8250	0.5
Syria	1.28	93000	7.3	62000	4.8
Turkey	5.34	110000	2.1	26000	0.5
UK	0.11	105000	95.5	6000	5.5
Portugal	0.63	40000	6.4	25000	4.0
Chile	1.09	16000	1.5	23000	2.1
Chinese Taipei	0.38	18900	5.0	8750	2.3
Bulgaria	0.59	21000	3.6	3000	0.5
Czech Rep.	0.15	11000	7.2	5000	3.3
Philippines	1.52	7180	0.5	6640	0.4
Poland	0.10	5000	5.0	8000	8.0
Malaysia	0.38	2000	0.5	5000	1.3
Estonia	0.001	500	50.0	500	50.0

Micro-irrigation can be combined with precision irrigation scheduling, enabling the application of water at a time and rate that are based on a crop's precise water requirement. With precision irrigation, scheduling is synchronized with weather and soil conditions, and a crop's evapotranspiration rate (Jones 2004) [10]. Precision irrigation saves water and money, and reduces runoff and energy consumption. In addition, by irrigating crops with a precise amount of water suited to the crop's growth stage, there is also the potential to increase crop yield (Cooley *et al*. 2009) [5].

The development of time domain and frequency domain reflectometry sensors which provide information on soil moister levels on a real-time basis has enabled the automation of irrigation systems. In the past, farmers decided when to irrigate based on intuition, weather, and physical plant/soil conditions. Sensors used for real-time irrigation scheduling take into account crop type, growth stage, soil type, and soil moisture status in order to take the guesswork out of irrigating and provide farmers with a more efficient and accurate way of determining when to apply water and for how long. Modern equipment allows for real-time data on soil water status to be available directly in the field, enabling farmers to make timely irrigation decisions.

In addition, with advanced technology, irrigation operations can be automatically triggered, consistently applying an accurate amount of water to crops (Avoiding unnecessary excess or deficits in water applications). Recent work by Jaria and Madramootoo (2011) [9] has shown how automated soil moisture sensors and weather measurements can be used in a computerized system, to determine irrigation triggers, thereby permitting the farmer to better and more precisely schedule drip irrigation applications. Improved knowledge about the interactions between the plant, soil, and water continuum has paved the way for innovative water regulating mechanisms.

For example, with deficit irrigation, water is applied below the crop's full water requirement (A percentage of a crop's evapotranspiration rate), reducing irrigated water use and conserving water. Water use effectiveness is increased by stressing crops, but only to a point which does not adversely affect yields (Fereres and Soriano 2006) [6].

Table 3: Drip vs surface irrigation-water saving and increase in yield (Shah 2011) [17]

	Yield (kg ha^{-1})			Irrigation		
Crop	**Surface**	**Drip**	**Increase (%)**	**Surface**	**Drip**	**Saving (%)**
Beet root	570	880	54	86	18	79
Bitter gourd	3200	4300	34	76	33	57
Brinjal	9100	14800	63	168	64	62
Broccoli	14000	19500	39	70	60	14
Chili	17100	27400	60	27	18	33
Cucumber	4230	6090	44	109	42	62
Okra	15500	22500	45	54	24	56
Onion	28400	34200	20	52	26	50
Potato	17200	29100	69	60	28	54
Radish	1050	1190	13	46	11	76
Sweet potato	4240	5890	39	63	25	60
Tomato	6180	8870	44	50	11	79
Banana	57500	87500	52	176	97	45
Grapes	26400	32500	23	53	28	47
Papaya	13000	23000	77	228	73	68
Pomegranate	3400	6700	97	21	16	24
Watermelon	8210	50400	514	72	25	65

Partial root zone drying is another strategy that can be employed with micro-irrigation for a more efficient use of irrigation water. The process requires that half of a crop's rooting system be exposed to alternate wetting and drying; essentially half of the root system is put in a drying state while the remainder remains irrigated. The alternating frequency is a function of the crop type, growth stage, and specific water requirement. This technique is based on an understanding of the mechanisms controlling transpiration, and requires sophisticated management and highly accurate monitoring (McCarthy *et al*. 2002) [14]. With this process there is a potential to reduce water use while increasing canopy vigour and maintaining yields in regions of water scarcity.

Micro-irrigation technology is enabling new and diverse methods of providing dependable irrigation in water-scarce regions. Treated and untreated wastewater can be applied in a manner which targets only suitable crops. Micro-irrigation is more appropriate than other irrigation methods for the reuse of wastewater because there is no aerosol generation and no wastewater comes into contact with plant foliage. There are also fewer problems with odours, ponding, and runoff. In addition, studies suggest that the nitrogen present in wastewater is better absorbed by plants and less likely to pollute groundwater when applied directly to plant roots.

When using wastewater with micro-irrigation it is necessary to ensure that emitters do not clog. Systems must be closely monitored to ensure a uniform application and full functionality (Casey *et al*. 1999) [4]. Another strategy for overcoming water shortages is the use of reverse osmosis in subsurface drip irrigation lines. Reverse osmosis technology enables the use of brackish water, frequently found in groundwater aquifers, as a source of irrigation water; allowing water that would normally be deemed unsuitable to be used for irrigating food crops.

Desalination is achieved using a semi-permeable reverse osmosis membrane within the drip line, supplying purified water to irrigated crops and preventing the accumulation of salts in the soil. Unlike conventional reverse osmosis systems which require the use of high- energy pumps, the transport of water across the reverse osmosis membrane within a drip line is driven by the matrix potential of the soil. Reverse osmosis subsurface drip irrigation systems are low flow, low pressure, and have an especially high-water use efficiency because water extraction is a direct function of the water requirement of the crop (Leslie 2010) [12].

Future Challenges

Numerous challenges need to be addressed to promote the adoption of micro-irrigation, especially in developing nations where small-scale farming is prevalent. Micro-irrigation is most effective for watering individual plants, trees, or row crops, but it has historically been considered unsuitable for densely planted crops like rice and other cereals (Brouwer *et al*., 1988) [2]. Consequently, farmers in regions reliant on these closely spaced crops have not been able to take advantage of micro-irrigation.

Nevertheless, with advancements in technology, efforts are underway to adapt micro-irrigation for a broader range of crops. The primary motivation behind these efforts is to enhance water utilization efficiency and bolster food security in areas with limited water resources, particularly in developing countries where cereal crops are dietary staples.

Rice, which is historically flood irrigated, consumes a lot of water. Drip irrigation reduces water consumption by 50-60%. Drip irrigation maintains soil moisture availability at or near the crop's water requirement. Non-flooding, on the other hand, increases weed prevalence, making herbicide use crucial when using drip irrigation in rice production (Soman 2012) [18]. Better understanding of the specialised water requirements of different cereal crops, as well as better suited equipment and technology, are required in regions that rely on these crops.

The advantages of employing a subsurface drip irrigation system over a surface drip irrigation scheme are being investigated. On the one hand, subsurface systems have a longer lifespan since fieldworkers and rats are less likely to harm or tamper with them. Crop yields with subterranean drip lines are equal to or better than those with surface drip lines, according to studies. Furthermore, the water and fertilizer need for buried systems are the same as or less than for surface irrigation. Some subsurface drip systems, on the other hand, are sophisticated, needing air entry ports and flushing manifolds.

The capacity of subsurface irrigation to maintain a dry soil surface is advantageous in some crop conditions (e.g., to prevent weed growth), but disadvantageous in others (e.g., for shallow-planted seed germination).

Another advantage is the use of subsurface irrigation in waste-water applications. This reduces odour issues, and the deeper placement of phosphorus in the soil profile improves plant uptake (Camp *et al*. 2000) [3].

More research is needed to find the most optimal placement of soil moisture sensors as we go towards automated irrigation scheduling. Sensors can currently only offer soil water status at a certain position and depth at a given site. As a result, sensor location is critical in order to offer a representative measurement for making complete irrigation selections. The location of the sensor in respect to the crop root zone is critical for turning irrigation systems on and off.

The use of satellite positioning systems, geographic information systems, automated machine guidance, and remote sensing technologies for precision irrigation scheduling and enhanced agricultural water management is a growing area of research (Joseph and Morrison 2006) [11].

Thermal vision captured by low-flying unmanned aerial vehicles, drones, aeroplanes, or satellites can assess the water content of soil or plant water status at high spatial resolution and, as a result, precisely trigger irrigation in a specific spot. As a result, crop yield and water conservation can be improved. This method can overcome barriers such as soil heterogeneity and field unpredictability to ensure that individual regions are irrigated according to their specific water needs.

However, the technology is still being refined to address concerns like as cloud interference and the requirement for regular imaging. To solve these challenges and efficiently control precision or variable rate irrigation, systems that use crop simulation models in addition to remote sensing have been proposed (Barnes *et al*. 2000) [1]. More study is needed to improve these techniques' accuracy and cost-effectiveness.

The application of nanotechnology and biotechnology in micro-irrigation has the potential to capitalise on water quality improvement, filtration techniques, and reduced emitter clogging. Nanomaterial-based biosensors have the ability to recognise, quantify, and monitor the presence of pollutants in real time. Nano-filtration membrane technology allows for particle identification and trapping at the nano-scale, as well as partial desalination. Furthermore, fouling of membranes and filters is decreased. Nanotechnology is also applied in the design of soil moisture sensors, resulting in excellent accuracy, rapid reaction rates, compact size, and resilience.

The issue with these advancements is putting research into practise. Improved cost-effectiveness, availability, and informed management will aid in increasing the use of these promising technologies (OECD, 2011) [15]. Despite the fact that technological advancement and simplification have lowered the overall cost of micro-irrigation systems, the technology remains pricey. A high level of technical skill is also necessary for proper system design, maintenance, and efficiency. Advancements that minimise prices, manpower, and make the initial system design and installation easier will make this technology more appealing to farmers.

Small farmers in underdeveloped nations have been slow to adopt micro-irrigation systems due to the large initial expenditure required to begin or transition to this practise. Furthermore, a lack of capital and experience, as well as crop specificity connected with present micro-irrigation methods, decrease its attractiveness (Varma *et al*. 2006) [19]. According to studies, farmers are rarely attracted by new technologies' potential for water and energy savings. Water is not metered in many countries, and power is subsidised, so farmers have no financial incentive to strive for resource conservation.

Furthermore, in nations where farmers have used surface irrigation for decades and are accustomed to having water provided through canals, they see no immediate value in culturally converting to other irrigation systems. Farmers are drawn to new technology that offer higher profits (Soman 2012) [18]. As a result, higher penetration of micro-irrigation technology in underdeveloped countries requires significant institutional support, promotion, product subsidies, and improved finance availability (Varma *et al*. 2006) [19].

Conclusions

In conclusion, this review paper has provided a comprehensive overview of the progress and challenges associated with micro-irrigation techniques. Over the years, micro-irrigation has emerged as a highly efficient and sustainable method for water resource management in agriculture, offering numerous benefits such as improved water use efficiency, increased crop yields, and reduced environmental impacts. However, it is evident that several challenges remain, including the high initial investment costs, maintenance requirements, and the need for proper training and education for farmers. Addressing these challenges will be crucial for the widespread adoption and continued success of micro-irrigation systems. As we move forward, it is essential to focus on research and innovation to develop more cost-effective and user-friendly technologies, as well as to promote policies and programs that support the adoption of micro-irrigation practices globally. By doing so, we can contribute to sustainable agriculture, food security, and water resource conservation in an increasingly water-scarce world.

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