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Contemporary Perspective of Drip Irrigation: A Review of Water Saving Crop Production

Shaikh Abdullah Al Mamun Hossain[1,2], Wang Lixue[1*], Md. Ektear Uddin[3], Liu Dan[1], Liu Haisheng[1] and Liu Siping[1]

[1]College of Water Conservancy, Shenyang Agricultural University, Shenyang, 110866, China.
[2]Department of Agricultural Engineering, Patuakhali Science and Technology University, Dumki, Patuakhali, 8602, Bangladesh.
[3]Department of Agricultural Extension and Rural Development, Patuakhali Science and Technology University, Dumki, Patuakhali, 8602, Bangladesh.

Authors' contributions

This work was carried out in collaboration between all authors. Author SAAMH designed the study and wrote the first draft of the manuscript. Authors WL, MEU, LD and LH managed the analyses of the study. Author LS managed the literature searches. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

Aims: The main focus of this paper was to review the present status and performance of drip irrigation system.
Place and Duration of Study: College of Water Conservancy, Shenyang Agricultural University, China. During March to July, 2016.
Methodology: This study compared drip irrigation with most common irrigation methods used for finding water-savings, efficient and sustainable agricultural production in arid and semi-arid regions on the basis available information.
Results: Increasing water demand in various sectors and inefficient water uses especially in agriculture, pose huge challenges in future water availability. Therefore, the future is seeking a more efficient method of water use. However, drip irrigation system is spreading rapidly all over the

**Corresponding author: E-mail: wlx1964@163.com;*

world as a water saving methods. Various types of crops grown under drip irrigation were compared with surface and sprinkler irrigation. Saline and reclaimed water application is also increasing alternatively as fresh water scarcity is increasing.

Conclusion: Review observation implies that, surface water irrigation will necessarily be reducing due to low efficiency and considerable conveyance losses.

Keywords: Drip irrigation status; performance; water use efficiency; water saving crops.

1. INTRODUCTION

Nowadays drip or trickle irrigation is considered most potential and water efficient system compared to other available irrigation systems because of global fresh water scarcity. Availability of fresh water is a major concern in crop production especially during dry-summer period in arid and semi-arid regions. The demand of world water has been consistently increasing in present-days in various sectors like municipal, industrial etc. which can often be at the cost of agriculture. To date agricultural sector is the largest consumer of water in the world [1]. Historically, early irrigation works were typically implemented to ensure human physical survival. In the absence of large population, industries and recreation there was not enough competition for water except between neighboring irrigators sharing the same water sources. The chief concern was then of crop production and feed the population. When the population increases with demand of water, the problems stemming from control of sources were settled politically, militarily or diplomatically. In 1800, the total worldwide irrigated area was about 8 million hectares. This has been increased five-fold during the 19th century because of various scientific and technical foundation for irrigation was developed tremendously [2]. In the 20th century, global irrigation grew from 40 to more than 270 million hectares (Fig. 1) [3]. Currently, India and China has nearly the same amount of irrigated cropland (57and 55 million hectares, respectively), which accounts for about 40% of the world's irrigated land. It is estimated that about 36% to 47% of the world's food is produced by irrigated production [3,4].

Currently, agriculture consumes 70% of world water withdrawals. The rest 21% and 9% is used in industrial and domestic activities [5]. By using this 70% water irrigated agriculture is producing 40% of the world's food crops on 20% of arable land. To accommodate food and fiber needs of growing population, agriculture sector has been expected to increase food production and improve water utilization efficiency. To satisfy 67% increase in food demand from 2000 to 2030 the projected water usage need to be increased 14% [6,7]. Based on irrigation experiences in 93 developing countries, FAO assessed the likely situation of irrigation in 2015 and 2030. The AQUASTAT information provided the estimation of base year of 1997/99 such as: values of land under irrigation, cropping patterns, cropping intensities in irrigation and national projections for irrigation development in the forthcoming years by 2030 as presented in Fig. 2 [8]. It has been expected to grow by about 14% more water than present requirements from the current year amounting from 2128 km^3/yr to 2420 km^3/yr by 2030 [8] and almost 3000 km^3/yr by 2050 indicates a net increase of 10% between now and 2050 [9].

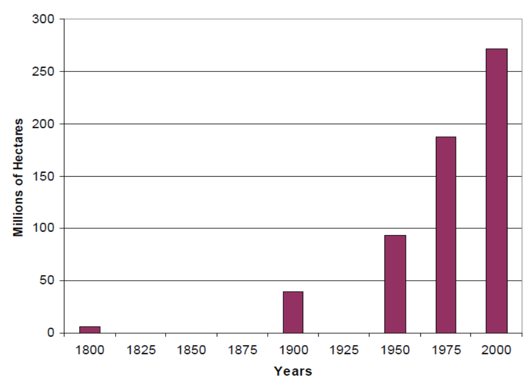

Fig. 1. Increase in irrigated area worldwide from 1800 to 2000 (Source: [3,10])

The report of International Water Management Institute (IWMI) Colombo indicated that, one-third of the world population will face water scarcity by the year 2025 [11]. The dry arid and semi-arid regions of East and South Asia, Middle-East and Sub-Saharan Africa already have high population density and peoples are living under poverty level [1,12]. Accordingly, withdrawal of excess water has been caused of groundwater mining, reduction of surface water resources, degradation of forest land and promotion of desertification [13]. Therefore, water saving and efficient irrigation technologies are of imperative needs.

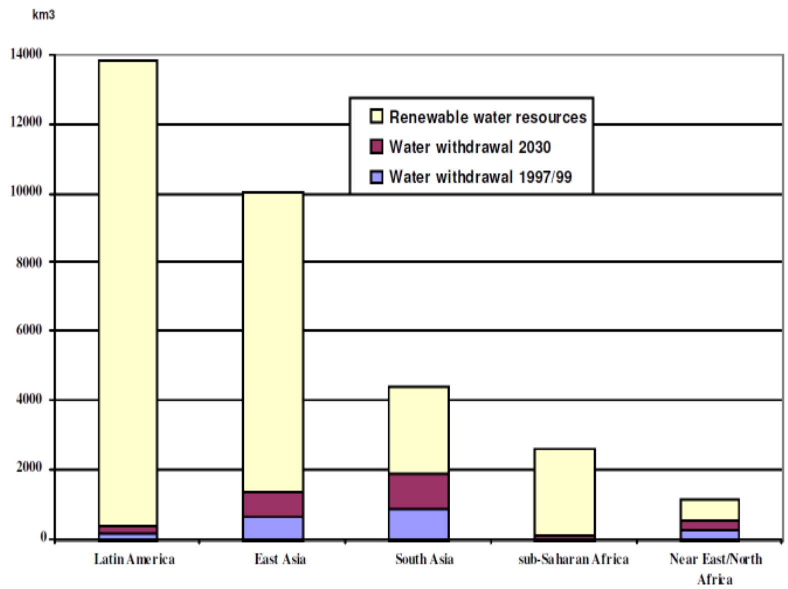

Fig. 2. Status of global water withdrawal for irrigation to food production from presents to forthcoming years by 2030 (Source: [8])

The idea, crops could do well with limited quantities of water, even better than with unlimited quantities in some situation suggested a more sophisticated water management than traditional practices. Different methods, viz. surface, sprinkler, micro irrigation and so forth are in competition in terms of cost convenience and efficient uses. Traditionally farmers over irrigate by flood, basin and furrow irrigation resulting high water losses and low water use efficiencies (WUE) and thus creating drainage and salinity problems [14]. Drip irrigation can help to increase irrigation water use potential that ensures equitable water distribution, can save water and energy input as well as increase crop yield. Crops yield adversely affected both in excess or deficit water supply. However, drip irrigation system in this sense is efficient because of reduced evaporation, runoff and deep percolation loss. But, this system demands a control and management involving knowledge on chemical parameters (electrical conductivity) that exclude many small farmers from developing countries. Efficient drip irrigation management demands fertigation, automation etc., that contribute to limit its use by all farmers, especially in developing countries. Surface drip irrigation is vulnerable to attack of rats and other animals in farms, especially during the dry season, limiting the time of the system and demanding the change of the drip line. This is a problem in some regions in Brazil. Sprinkler irrigation is less vulnerable, but it's relying on huge evaporation losses. The cost of the system limits its use to valuable crops, as fruits, coffee, vegetables etc. In Brazil, for example, drip irrigation is not used to extensive crops such as corn, bean, wheat, soybean etc. Despite the revision indicate an extensive literature reporting the use of drip irrigation to corn it is supposed that there is a difference between scientific use of drip irrigation and commercial drip irrigation use. In some countries of Latin America (Argentine, Brazil, Paraguay, Bolivia and Peru) drip irrigation is not used to corn or soybean, because the costs of the system. Center pivot and sprinkler are systems with wider uses.

Drip irrigation technology has several advantages over sprinkler and other irrigation techniques. Drip provides precise water control dissolved fertilizers, application facilities and therefore cost effective. However, water scarcity is not only the reason for which this study advocates drip irrigation. Technological, economic aspects, training and expertize of farmers are the driving forces to be considered in Water Saving Crop Production. Consequently, many developing countries are promoting drip irrigation and center pivot systems instead of conventional sprinkler system, although these systems are comparatively expensive to install and maintain [15]. In addition, the use of drip irrigation techniques is inevitable in the near

Table 1. Location based research of different crops practices under drip irrigation

Crops	Study location/Country										Total crops
	USA	China	Egypt	India	Turkey	Saudi Arab	Pakistan	Iran	Tunisia	Other country	
Corn	4	2	5	-	1	-	2	2	1	1	18
Cotton	4	8	-	3	3	-	-	-	-	2	20
Tomato	1	1	-	1	-	2	-	-	1	5	11
Potato	-	-	1	-	1	-	-	1	2	2	7
Others	4	2	1	5	1	2	1	1	2	10	29
Country total	13	13	7	9	6	4	3	4	6	20	-

future because of the salinity problem caused by traditional irrigation methods [16].

According to above debate, agricultural crop production system changes over the last century have tried to save water and substantial increase in food security preferably through drip irrigation. Thus, it becomes necessary to enumerate the performance of present drip irrigation systems, both on the drawing board, as a design and management criterion, and in the field as effectiveness of water-saving, as an operating criterion. Therefore, it is very important to recognize the consequences of drip irrigation status in worldwide based on water saving crop production. The present paper aims to review the contemporary perspective of drip irrigation system both in surface (DI) and subsurface (SDI) associated with other irrigation that could be effective in arid and semi-arid reasons of the world.

2. REVIEW APPROACHES

In this review discussions were undertaken on the contemporary perspectives of drip irrigation. The cases of water saving crop production started from globally published various scientific works specific to surface drip (DI) and sub-surface drip (SDI) irrigation application. The prominence activities for different crop cultivation using drip irrigation system were documented and assessed from the results of published works. The information and statistics were collected from secondary sources such as books, reports, reviews, thesis, scientific & index journals and internet search etc. The thematic approach as followed by Camp [17] was used index the documents and information from various resources. The principal emphasis was concentrated on literature in appropriate scientific journals that reported results, statistics of genuine and experimental studies. The discussion on perspectives of drip irrigation's efficiency moves around the design & setting and way of implementation together with soil texture, water, fertilizer, growth and yield parameters of different crops, in comparison with other irrigation practices. This study reviewed the findings of 84 scientific journals to assess the contemporary view of global drip irrigation usage for different crop production including practiced or experimental location. The desired articles were accumulated from randomly using different search engines like Google, Yahoo, Bing etc. together with various social media access like Researchgate, Academia.edu, Linkedin and so forth. For establishing a statistical bench we assigned score 1 (one) for each experimental or research location and correspondent for each type of crop can view perspective research status on drip irrigation system of this review study as shown in Table 1.

3. RESULTS AND DISCUSSION

The review results of this study have been discussed under the following sub-heads: Drip irrigation methods, Different cropping under drip irrigation, Perspectives of drip irrigation, Alternative water use in drip irrigation and Drip irrigation model practice. This review shows the present perspectives of some countries practicing drip irrigation crop production such as USA, China, India, Egypt, turkey and 19 more different countries with varieties of crops practices such as corn, cotton, tomato, potato etc. This study show that, among 25 randomly selected countries more than 15% drip irrigation crops are practiced China and USA respectively. A considerable practice was also reported in India, Egypt, Turkey, Tunisia, Pakistan and Saudi Arab. The leading crop practices under drip irrigation system was cotton (24%) followed by corn (21%), tomato (13%) and potato (8%). The other crops under drip irrigation system constitute the 34% space in world (Fig. 3).

Table 2. Summary of drip design parameter for cereal crops and conditions associated with other irrigation methods used globally

Types of crop	Study Location/ Country	References	Irri. Meth. Used*	Lateral/Drip setting			Water suppl.§	Irrigation scheduling			Soil type‖	Fert. Appl	Water req. cal.
				Type **	Depth (m)	Spacing (m)		Timing	MSM †	Other‡			
Corn/Maize	Tunisia	[18]	DI, SDI	DT	.05-.35	0.8	FW	x			SC		x
Corn	USA	[19]	SDI	TD	0.4	1.52	FW	x	NP		SiL	x	x
Corn	USA	[20]	SDI	DDT	0.4-.45	1.5-3.0	FW	x	NP		SiL	x	
Corn	USA	[21]	SDI	TD	0.4	1.5	FW				SiL	x	
Sweet Corn	USA	[22]	SDI	DT	0.28	1.2	FW	x	T		SL		
Corn	Egypt	[23]	DI, SDI, F			0.75	FW		ODM		L		x
Corn	Egypt	[24]	SDI	TLD	0.2	0.6	FW		TDR		SCL		x
Corn/Maize	Egypt	[25]	DI, SDI		0.2	0.75	FW				SL	x	x
Corn/Maize	Egypt	[26]	DI			0.7	FW	x		EP	S	x	
Corn	Egypt	[27]	DI	PE		1.4	FW	x	ODM		S	x	x
Sweet Corn	Malaysia	[28]	DI	PP			FW	x	SMS		SC	x	
Corn	Pakistan	[29]	DI, F			0.66	FW	x			Cal		
Corn/Maize	Pakistan	[30]	DI			0.74	FW	x			SCL		x
Corn	Iran	[31]	DI, F	PT		0.75	FW	x		EP	S	x	x
Corn/Maize	Iran	[32]	DI				FW				SiCL		x
Corn	Turkey	[33]	DI	PE		0.7-2.1	FW	x	NP, T		C	x	x
Seed Maize	China	[34]	DI	TLD			FW					x	
Waxy Maize	China	[13]	DI	DT		1.4	SW		T		S	x	
Wheat	India	[35]	DI, B	PVC		1.66	FW	x		EP	CL	x	x
Wheat	Morocco	[36]	DI, B			1.0	FW	x			SiC	x	x
Aerobic rice	India	[37]	DI, SDI	PVC		0.6-1.0	FW	x		EP		x	x
Peanut	USA	[38]	SDI	DT	0.3	0.9-1.8	FW	x			SL		x
Fodder/Cowpea	Nepal	[39]	DI, F			0.5	FW	x			L	x	
Alfalfa	Saudi Arabia	[40]	SDI	RB	0.1	0.4	FW				SCL		

** Irrigation method code definition (Tables 2-5): DI = Surface Drip, SDI = Sub-surface Drip, CB = Check basin, FL = Flood, RB = Ring basin, F = Furrow, S = Sprinkler and B = Boarder irrigation.*

*** Type code definition: DT = Drip tube/tape (Twin-wall/GR type), TD = Thin-wall dripper lines, DDT = Dual-chamber drip tape, TLD = Turbulence labyrinth/ Turbulent flow drip tape, PT = Plastic tape pipe, PE = Polyethelene (pipe manifolds/twin-wall), PP = Poly pipe, RB = Rain Bird Ld 06.*

§ Water supply code definition (Tables 2-5): FW = Fresh water, SW = Saline water, WW = Waste water, B = Brackish water.

† MSM (Measured Soil Moisture Content): TDR = Time domain reflector, NP = Neutron Probe, T = Tensiometer, SMS = Soil moisture sensor.

‖ Soil type code definition: SC = Sandy clay, SiL= Silt loam, L = Loamy, SCL = Sandy clay-loam, SL = Sandy loam, Cal = Calcareous soil, SiCL= Silt clay loam, S = Sandy, C = Clay. SiC = Silt clay, CL = Clay-loam

Table 3. Summary of drip design parameter for cash crops and conditions associated with other irrigation methods used globally

Types of crop	Study Location/ Country	References	Irri. Meth. Used*	Lateral/Drip setting			Water suppl.§	Irrigation scheduling			Soil type‖	Fert. Appl	Water req. cal.
				Type **	Depth (m)	Spacing (m)		Timing	MSM †	Other‡			
Cotton	China	[41]	DI	DT		0.8	SW		T		D	x	
Cotton	China	[42]	DI	WLT		0.9	FW		TN		ML	x	x
Cotton	China	[43]	DI			0.7	FW,SW		NP	MP	LS	x	
Cotton	China	[44]	DI	DT		1.25	FW	x			SL	x	
Cotton	China	[45]	DI	DT		0.9, 1.8	BW,SW		ODM		SiC		
Cotton	China	[46]	DI	PT		1.2	FW	x		AWDS	L		x
Cotton	China	[47]	DI	DT		0.9	FW		TDR		L		x
Cotton	USA	[48]	SDI	PT	0.26	0.76	FW	x	NP		S	x	x
Cotton	USA	[49]	SDI	DT	0.26	0.76	FW		NP	EP	SL	x	x
Cotton	USA	[50]	DI			0.75-1.0	FW		T		CL	x	
Cotton	USA	[51]	SDI, S	DT	0.25	0.91	FW				SL	x	
Cotton	Syria	[52]	DI, F, B	PE		0.75-0.8	FW	x			LC		x
Cotton	India	[53]	DI, CB	PE		0.67, 1.0	FW	x		EP	LS	x	
Cotton	India	[54]	DI, F			1.5	SW	x			C	x	x
Cotton	India	[55]	DI, FL				FW					x	
Cotton	Turkey	[56]	DI, F, S	PE		0.7	FW			EP	C	x	
Cotton	Turkey	[57]	DI	PE		0.7	FW		ODM		L	x	x
Cotton	Turkey	[58]	DI	PE		0.7	SW		PM	EP	C	x	x
Cotton	Uzbekistan	[59]	DI, F	DT		0.6	FW	x	NMM		SiL	x	x
Sugar beet	Italy	[60]	DI, F			0.6	FW		TDR		CL	x	x
Sugarcane	Pakistan	[61]	SDI	TT	0.15	1.52	FW		T		SL	x	x
Sugarcane	India	[55]	DI, F				FW					x	

*** Type code definition: DT = Drip tube/tape (Thin-wall/Twin-wall/GR type), PT = Plastic tape pipe, PE = Polyethelene (pipe manifolds/twin-wall), WLT = Wing labyrinth drip tape, TT = T-tape branded tube/Bladder type.*

† MSM (Measured Soil Moisture Content): TDR = Time domain reflector, NP = Neutron Probe, T = Tensiometer, SMS = 10 HS, Soil moisture sensor, TN = USA CPN 503DR.9 Type Neutron tube, ODM = Oven dry method, PM = Pressure Membranes, NMM = Neutron moisture meter.

‡ Other code definition (Tables 2-5): EP = Class-A Evaporation pan, MP = Moisture probe, G = Geotextile, AWDS = Automatic water depth sensor, L = Lysimeter, WS = Watermark sensors, G = Geotextile, FDR = Frequency Domain Reflectometry.

‖ Soil type code definition: C = Clay, SiL= Silt loam, S = Sandy, L = Loamy, CL = Clay-loam, D = Desert soil, SL = Sandy loam, LC = Loamy clay, LS = Loamy- sandy, ML = Medium loamy, SiC = Silt clay

Table 4. Summary of drip design parameter for vegetable crops and conditions with other irrigation methods used globally

Types of crop	Study Location/ Country	References	Irri. Meth. Used*	Lateral/Drip setting			Water suppl.§	Irrigation scheduling			Soil type‖	Fert. Appl	Water req. cal.
				Type **	Depth (m)	Spacing (m)		Timing	MSM †	Other‡			
Tomato	USA	[62]	SDI, S	LF	0.2	1.67	SW		NM				x
Tomato	Saudi Arabia	[63]	DI, SDI	TL	0.2-.25	1.0	SW				CalS		x
Tomato	Saudi Arabia	[64]	DI, SDI	DT	0.25	0.5	FW,SW		ODM		CalS	x	x
Tomato	Macedonia	[65]	DI, F	PC		0.8	FW	x			Col	x	x
Tomato	China	[66]	SDI	PE	0.2-0.4	0.5	FW		T		SCL		x
Tomato	India	[67]	DI, F	PC		0.45	FW	x	NM		CL, C	x	x
Tomato	Spain	[68]	DI		0.05	1.5	FW		TDR		Cal	x	x
Tomato	Tunisia	[69]	DI, SDI		0.3	1.0	SW				SiC		
Tomato	Bangladesh	[70]	DI			0.6	FW	x		L	SiCL	x	x
Tomato	Ethiopia	[71]	DI	DT		1.0	FW	x					x
Eggplant	Tunisia	[18]	DI, SDI	DT	0.2	1.2	FW		TDR		SC		x
Eggplant	India	[53]	DI, F	PE		0.6	FW	x		EP	LS	x	x
Eggplant	Turkey	[72]	DI, SDI		0.25	0.9	FW		NP		CSi	x	x
Potato	Iran	[73]	DI, F	TT		0.3	FW			EP	SiC	x	x
Potato	Egypt	[74]	DI, SDI	PE	0.15	0.4	FW	x	ODM	EP	S	x	x
Potato	Turkey	[75]	DI, SDI		0.15	0.7	FW	x	ODM		CL, L	x	x
Potato	Tunisia	[76]	SDI	DT	.05-.30	0.8	FW	x	ODM		SL		x
Potato	Tunisia	[77]	DI, SDI	PE	0.15	0.7	SW	x	ODM		S	x	x
Potato	Iraq	[78]	DI, F	PC		0.7	FW				SiCL	x	x
Potato, Onion	Morocco	[79]	DI			-	FW				SL		x
Chilli	India	[55]	DI, FL				FW					x	
Onion	Kenya	[80]	DI			0.3	FW	x	ODM		SL	x	x
Onion	Tunisia	[81]	DI			0.5	SW	x			S	x	x
Cucumber	Syria	[82]	DI, F			1.5	FW	x	NP		C	x	x
Carrot	Poland	[83]	DI, SDI	TT	0.05	0.67	FW			WS	SL	x	
Cauliflower	USA	[84]	SDI	DT	0.15	1.02	FW	x	T		SL	x	

*** Type code definition: DT = Drip tube/tape (Thin-wall/Twin-wall/GR type), PE = Polyethelene (pipe manifolds/twin-wall), LF = Low-flow drip tape, TL = Thin-layer dripper tube, PC = pressure-compensated, TT = T-tape branded tube/Bladder type.*

† MSM (Measured Soil Moisture Content): TDR = Time domain reflector, NP = Neutron Probe, T = Tensiometer, ODM = Oven dry method, NM = Neutron moisture meter,

‖ Soil type code definition: C = Clay, CSi = Clay silt, CL = Clay-loam, SC = Sandy clay, S = Sandy, SL = Sandy loam, L = Loamy, SCL = Sandy clay-loam, LS = Loamy-sandy, Cal = Calcareous soil, CalS = Calcareous sandy, Col = coluvial, SiC = Silt clay, SiCL= Silt clay loam

Table 5. Summary of drip design parameter for fruit crops and conditions associated with other irrigation methods used globally

Types of crop	Study Location/ Country	References	Irri. Meth. Used*	Lateral/Drip setting			Water suppl.§	Irrigation scheduling			Soil type‖	Fert. Appl	Water req. cal.
				Type **	Depth (m)	Spacing (m)		Timing	MSM †	Other‡			
Apple tree	China	[85]	DI, SDI	PE	0.4	-	FW	x			A	x	
Olive tree	Spain	[86]	DI, SDI		0.5	1.0	FW,SW	x	CP		SL		x
Orange tree	Egypt	[87]	DI	DT		-	FW			G	S		
Pear Trees	China	[88]	DI, FL			2.0	FW	x	CP	EP	SL		x
Lemon tree	Spain	[89]	DI, SDI	NTA	0.4	3.0	FW	x		FDR	Ar	x	x
Sapota tree	India	[90]	DI, RB			5.0	FW	x			SL		x
Banana	USA	[91]	DI			0.6	FW			EP	C	x	x
Banana	India	[55]	DI, F				FW					x	
Cucumber	Syria	[82]	DI, F			1.5	FW	x	NP		C	x	x
Melons	Israel	[92]	DI, SDI	NTA	0.2, .4	0.4	WW				C	x	
Tomato	USA	[62]	SDI, S	LF	0.2	1.67	SW		NM		-		x
Tomato	Saudi Arabia	[63]	DI, SDI	TL	0.2-.25	1.0	SW				CalS		x
Tomato	Saudi Arabia	[64]	DI, SDI	DT	0.25	0.5	FW,SW		ODM		CalS	x	x
Tomato	Macedonia	[65]	DI, F	PC		0.8	FW	x			Col	x	x
Tomato	China	[66]	SDI	PE	0.2-0.4	0.5	FW		T		SCL		x
Tomato	India	[67]	DI, F	PC		0.45	FW	x	NM		CL, C	x	x
Tomato	Spain	[68]	DI		0.05	1.5	FW		TDR		Cal	x	x
Tomato	Tunisia	[69]	DI, SDI		0.3	1.0	SW				SiC		
Tomato	Ethiopia	[71]	DI	DT		1.0	FW	x					x
Zinnia elegant	Saudi Arabia	[93]	DI, SDI	DT	0.25	0.45, .5	FW				S	x	x
Cantaloupe	Iran	[94]	DI, F			1.5	FW	x		EP	CL	x	x

*** Type code definition: DT = Drip tube/tape (Thin-wall/Twin-wall/GR type), PE = Polyethelene, LF = Low-flow drip tape, TL = Thin-layer dripper tube, NTA = Netafim, Tel Aviv, PC = pressure-compensated,*

† MSM (Measured Soil Moisture Content): TDR = Time domain reflector, NP = Neutron Probe, CP = capacitance probe, T = Tensiometer, ODM = Oven dry method, NM = Neutron moisture meter.

‖ Soil type code definition: C = Clay, S = Sandy, SCL = Sandy clay-loam, CL = Clay-loam, A = alluvial, Ar = Aridisol, SL = Sandy loam, SL = Sandy-loam, CalS = Calcareous sandy, SiC = Silt clay, Col = coluvial

Table 6. Summary of quantitative outcomes for cereal crops reported on perspective crops production using drip and others irrigation methods

Types of crop	Irri. Meth. Used	Growth Index‡					Yield	WUE/WP‖	Others §	Impr. Y. & Eco. Ev. †	References
		PH	LN/SD	LAI/LA	BW/SW	RW					
Corn/Maize	DI, SDI	x		LAI			x			Y	[18]
Corn	SDI						x	x			[19]
Corn	SDI						x	x		EE	[20]
Corn	SDI						x	x	DP	Y	[21]
Sweet Corn	SDI						x		ISP		[22]
Corn	DI, SDI, F	x	LN	LA			x	x		EE	[23]
Corn	SDI	x	LN, SD	LA		x	x	x	EL, GW	Y	[24]
Corn/Maize	DI, SDI	x	LN		x	x	x	x		Y	[25]
Corn/Maize	DI	x		LAI	x		x	x	EL	Y	[26]
Corn	DI						x	x	EW, GW		[27]
Sweet Corn	DI				x	x	x		ClC, EW	Y	[28]
Corn	DI, F	x			x		x		HI	Y	[29]
Corn/Maize	DI	x					x	x	GR		[30]
Corn	DI, F				x		x	x		Y	[31]
Corn/Maize	DI						x	x		Y	[32]
Corn	DI				x		x	x	HI	Y	[33]
Seed Maize	DI	x	LN	LAI	x		x				[34]
Waxy Maize	DI	x		LAI	x		x	x	GR		[13]
Wheat	DI, B				x		x	x	HI		[35]
Wheat	DI, B			LAI			x	x	NDVI	Y	[36]
Aerobic rice	DI, SDI			LAI		x	x	x	RL, RMD, HI		[37]
Peanut	SDI						x		KSD	Y	[38]
Fodder, Cowpea	DI, F				x		x	x	UC, DU		[39]
Alfalfa	SDI	x			x		x	x	NT, LSR, SMD		[40]

‡ Growth Index code definition (Tables 6-9): PH = Plant height (cm), LN = Leaf number, SD = Stem diameter (mm), LA = Leaf area (cm^2), LAI = Leaf area index, BW/SW = Biomass dry weight/shoot dry weight (g/plant), RW = Root dry weight (g/plant).

‖ Code definition: WUE/WP (Tables 6-9) = Water use efficiency/ Water productivity

§ Others code definition: DP = Dry matter production, ISP = Irrigation system performance, GW = Grain weight (g/Ear/plant), EL = Ear length, EW = Ear weight (g/plant), ClC = Chlorophyll content, HI = Harvest index, GR = Germination rate (no./m^2), NDVI = Normalized difference vegetation index,, RL/RMD = Root length/mass density, KSD = Kernel size distribution, UC = Uniformity coefficient, DU = Distribution uniformity, NT = Number of tillers, LSR = Leaf stem ratio, SMD = Soil moisture distribution pattern,

† Improved yield due to using drip irrigation and others several factors influenced and Economic Evaluation code definition (Tables 6-9): Y = Improved Yield, EE = Economic Evaluation

Table 7. Summary of quantitative outcomes for cash crops reported on perspective crops production using drip others irrigation methods

Types of crop	Irri. Meth. Used*	Growth Index‡					Yield	WUE/WP‖	Others §	Impr. Y. & Eco. Ev. †	References
		PH	LN/SD	LAI/LA	BW/SW	RW					
Cotton	DI				x		x	x	NUE		[41]
Cotton	DI	x	SD	LAI			x	x		Y	[42]
Cotton	DI								WCC		[95]
Cotton	DI			LAI			x	x	NMS		[45]
Cotton	DI						x		RLD	Y	[45]
Cotton	DI						x		SDSR	Y	[46]
Cotton	DI	x		LAI					Kc, ETcact		[47]
Cotton	SDI				x	x	x		RSR, RLD	Y	[48]
Cotton	SDI	x					x	x	LS	Y	[49]
Cotton	DI	x					x	x	CWU(ET)	Y	[50]
Cotton	SDI, S						x		HU	Y	[51]
Cotton	DI, F, B	x					x		NP, HNR	Y	[52]
Cotton	DI, CB						x	x	BWUF	EE	[53]
Cotton	DI, F	x					x	x	BP, NUE	Y	[54]
Cotton	DI, FL	x					x	x	BP	Y, EE	[55]
Cotton	DI, F, S						x		BCR	EE	[56]
Cotton	DI						x	x	SR	Y	[57]
Cotton	DI			LAI	x		x	x	BP, FL, FS	EE	[58]
Cotton	DI, F	x		LAI	x		x	x	HI, NUE		[59]
Cotton	DI, F	x					x	x	BP, NP, HU		[60]
Sugar beet	SDI			LAI	x	x	x		PR, SC, SQ & P		[61]
Sugarcane	DI, F						x		NT, HI	EE	[55]
Sugarcane	DI						x		BCR	EE	[41]

§ Others code definition: HI = Harvest index (GW/BW), NUE = Nitrogen use efficiency, WCC = Water Consumption characteristics, NMS = Numerical model simulation, RLD = Root length density, SDSR = Spatial distribution of salinity in root zone, Kc = Crop coefficient, ETc act = Actual Evapotranspiration, RSR = Root-shoot ratio, LS = Length of season, CWU = crop water use, HU = Heat unit, NP = Node per plant, HNR = Height to node ratio, BWUF = Beneficial water use fraction, BP = Branches per plant/Boll per plant, BCR = benefit cost ratio, SR = Shedding ratio, FL = fiber length, FS = fiber strength, PR = Leaf photosynthetic rate, SC = Stomatal conductance, NT = Number of tillers, SQ & P = Sugar quality and productivity

Table 8. Summary of quantitative outcomes for vegetable crops reported on perspective crops production using drip and others irrigation methods

Types of crop	Irri. Meth. Used*	Growth index‡					Yield	WUE/WP‖	Others§	Impr. Y. & Eco. Ev. †	References
		PH	LN/SD	LAI/LA	BW/SW	RW					
Tomato	SDI, S						x		SS, C, IE	Y, EE	[62]
Tomato	DI, SDI						x	x			[63]
Tomato	DI, SDI						x	x	SSDC		[64]
Tomato	DI, F				x		x	x	NFP, FW	Y	[65]
Tomato	SDI					x	x	x	RSR		[66]
Tomato	DI, F				x		x	x	CT	Y	[67]
Tomato	DI						x		FW		[68]
Tomato	DI, SDI				x		x	x	CD, NL, NUE		[69]
Tomato	DI			LA					ClC, MNC		[70]
Tomato	DI	x					x	x	FW, FL, FD	Y, EE	[71]
Eggplant	DI, F	x		LA			x		FW		[18]
Eggplant	DI, SDI						x	x	NFP, FW		[53]
Eggplant	DI, F			LAI	x		x	x	FL, FW, SS		[72]
Potato	DI, SDI				x	x	x	x	TS, LW, SW	Y	[73]
Potato	DI, SDI				x		x	x	NT, TW, FUE	Y	[74]
Potato	SDI						x	x	NT, TW, TS	EE	[75]
Potato	DI, SDI							x	SMD		[76]
Potato	DI, F						x	x	NT, TW, TS		[77]
Potato	DI						x	x	TS, TW, NT		[78]
Potato, Onion	DI, FL						x		DU, IE		[79]
Chilli	DI						x		BCR	EE	[55]
Onion	DI						x	x	OBS, OBW, SI		[80]
Onion	DI, F						x	x	OBN, OBW		[81]
Cucumber	DI, SDI						x	x	SMD, LS		[82]
Carrot	SDI					x	x		RL	Y	[83]
Cauliflower	SDI, S				x		x		NUE	EE	[84]

§ Others code definition: SS = Soluble solid, C = Colour, ClC = Chlorophyll content, NUE = Nitrogen use efficiency, RL = Root length, SMD = Soil moisture distribution pattern, RSR = Root-shoot ratio, LS = Length of season, BCR = benefit cost ratio, FL = Fruit length, MNC = Mineral nutrient content, IE = Irrigation efficiency, SSDC = Soluble salt distribution contour, NFP = Number of fruits/fall fruits per tree, FW = Fruit weight (g)/width (cm), FD = Fruit diameter (mm), CT = Canopy temperature, CD = Cumulative drainage, NL = Nitrate leaching, TS = Tuber size (mm), NT = Number of tuber per plant, TW = Tuber weight (g/plant), LW = Leaf weight (g), SW = Stem weight (g), DU = Distribution uniformity, OBS = Onion bulb size (mm), OBN = Onion bulb no. (no./ha) OBW = Onion bulb weight (g)

Table 9. Summary quantitative outcomes for fruits crops reported on perspective crops production using drip and others irrigation methods

Types of crop	Irri. Meth. Used*	Growth index‡					Yield	WUE/WPǁ	Others§	Impr. Y. & Eco. Ev. †	References
		PH	LN/SD	LAI/LA	BW/SW	RW					
Apple tree	DI, SDI				x	x		x	PR, TR, SC		[85]
Olive tree	DI, SDI						x	x			[86]
Orange tree	DI						x		MDC, NFFT		[87]
Pear Trees	DI, FL				x		x	x	SWP, SL, SS		[88]
Lemon tree	DI, SDI						x	x	TCA, NFP, FW		[89]
Sapota tree	DI, RB	x					x	x	Girth, NB		[90]
Banana	DI						x		BW, FD, FL		[91]
Banana	DI, F						x		BCR	EE	[55]
Cucumber	DI, F						x	x	SMD, LS		[82]
Melons	DI, SDI						x		FW, TS, MP		[92]
Tomato	SDI, S						x		SS, C, IE	Y, EE	[62]
Tomato	DI, SDI						x	x	SSDC		[63]
Tomato	DI, SDI				x		x	x	NFP, FW	Y	[64]
Tomato	DI, F					x	x	x	RSR		[65]
Tomato	SDI				x		x	x	CT	Y	[66]
Tomato	DI, F						x		FW		[67]
Tomato	DI				x		x	x	CD, NL, NUE		[68]
Tomato	DI, SDI			LA					ClC, MNC		[69]
Tomato	DI	x					x	x	FW, FL, FD	Y, EE	[71]
Tomato	DI, SDI						x		FW		[96]
Zinnia elegant	DI, SDI	x			x	x	x		NB, FD, NFP		[93]
Cantaloupe	DI, SDI						x	x	NFP,FW, FT		[94]

§ Others code definition: PR = Leaf photosynthetic rate, TR = Transpiration rate, SC = Stomatal conductance, ClC = Chlorophyll content, NUE = Nitrogen use efficiency, SMD = Soil moisture distribution, RSR = Root-shoot ratio, LS = Length of season, SL = Shoot length, BCR = benefit cost ratio, FL = Fruit length, SS = Soluble solid, C = Colour, MNC = Mineral nutrient content, MDC = Moisture distribution contour, NFP/NFFT = Number of fruits/flower/ fall fruits per tree, FW = Fruit weight (g)/width (cm), FT = Fruit thickness, BW = Bunch weight, FD = Fruit/Flower diameter (mm), CT = Canopy temperature, CD = Cumulative drainage, NL = Nitrate leaching, SWP = Surface Wetted Percentage, TCA = Trunk cross-sectional area, NB = Number of branches, TS = Toxicity symptoms, SSDC = Soluble salt distribution contour, IE = Irrigation Efficiency, MP = Microbiological parameters (E. coli. Fecal coliforms, bacteria & fungi)

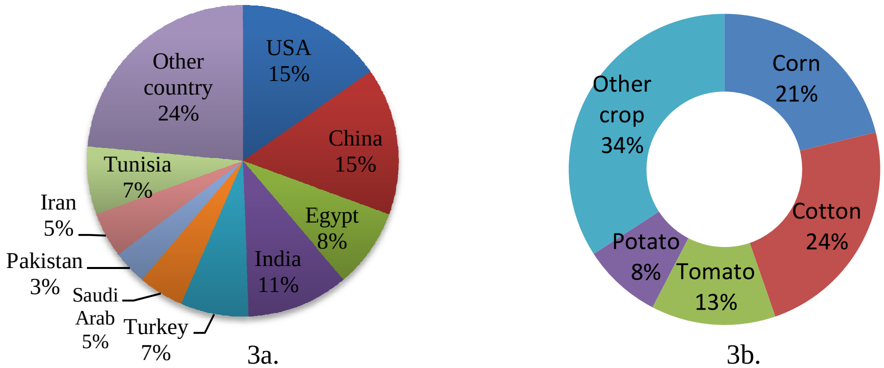

Fig. 3. Global drip irrigation status, (3a) country leading drip irrigation research and (3b) crops dominant in drip irrigation research

3.1 Drip Irrigation Methods

Drip irrigation is also known as trickle or micro-irrigation in which water delivered at or near the root zone of plants in drop by drop. Two ways: surface drip irrigation (DI) and Sub-surface drip irrigation (SDI) methods are used globally for irrigated agriculture. The DI and SDI system is on present potential for various crop production, yield and water use efficiency and intended for multiple-year use. DI is used more intensively than SDI. However, micro-irrigation probably started with water application below the soil surface [97]. Experimental evidences showed that despite some limitations, SDI has advantages over DI methods [98,99]. SDI also termed as seepage irrigation that has been used for many years in areas with high water table. It is a method of artificially raising the water table to allow the soil to be moistened from below the plan root zone [100]. This method can be more efficient with proper management of the system by minimizing evaporation and runoff losses. It reduces excess use of water by allowing water to drip slowly to roots of plants, either onto soil surface or directly into root zone, through a network of valves, pipes, tubing, and emitters use [101]. Present surface drip irrigation often use a combination of plastic mulch for further reducing evaporation losses. This system is often treated as temporary because the dripline can retrieved and recycled yearly. This is a method of effective irrigation system depending on how the emitters are placed in the pvc pipe or plastic polyethylene distribution line. Water applied from the close and equally spaced holes usually runs along the line and forms a continuous wetting pattern [102]. Several advantages of using drip irrigation such as: water saving since only those areas directly around plant root zones are irrigated, plant undergoes less stress from variations in soil moisture, slow application rate prevents excess surface water build-up, reduces evaporation loss and weed growth reduces because areas between plants are not irrigated well.

3.2 Different Cropping Under Drip Irrigation

A crop and country based summery of some study on drip design parameter, other irrigation types, irrigation scheduling, soil types, fertilizer and water requirements calculation etc. has been placed in Tables 2-5. Review shows that drip irrigation method is practiced in many crops such as corn [26,32,103,104], wheat [35,36], Aerobic rice [37] etc. In case of cash crops most studies were found on cotton [42,43,46] and Sugarcane [61]. Various vegetables crops were also irrigated by drip irrigation such as tomato [70,79], potato [73,76] and eggplant [72,103]. Some fruits and crops such as melon, banana [80,91], apple, pear, lemon, orange [85,88,89] etc. were also reported in drip irrigation research. The authors were compared DI, SDI and others different traditional irrigation system for various crop practices. The review results revealed varieties of drip tape system in practice that also set the emitters at different space along the drip line and different layer of soil depth in case of SDI irrigation (Tables 2-5). The authors describe various methods of soil moisture measurement system and estimation process of crop water requirements and irrigation schedule using different technique. Several author applied different fertilizer (Organic or inorganic) according to soil nutrient condition (Tables 2-5).

3.3 Perspectives of Drip Irrigation

The findings show that drip irrigation is preferred for many crops around the globe. The summary of investigational evidence reported on drip irrigation, its application in different crops and its comparison with other irrigation system are shown in Tables 6-9. The authors obtained and evaluated the effects of drip irrigation and in several cases with fertilization on growth index, yield and water use efficiency (WUE). The study also compared drip with traditional irrigation system on the basis of improve yield and in some cases economic evaluation. In most of the cases, drip irrigation reported significant increase in yield compared to other irrigation practices. Yield of corn increases due to air injection [24]. Highest average grain yield was 12.9 t/ha [31], compared to DI and SDI irrigation treatments and DI and furrow irrigation treatments respectively. The corn yield increased with increasing drip irrigation rates [27]. Highest grain yield and the lowest one were obtained with injecting fertilizers through drip irrigation treatment at 1.2 and of 0.6 crop evapotranspiration [26]. Same amount of water with N application through drip irrigation increased the seed cotton yield [53]. The highest eggplant yield under drip obtained at $D_{0.75}$ and N_{120}, which was 23% higher and 25% water saving as compared with furrow irrigation at N_{150} [105]. Application of 440 mm/ha water in two days interval with straw mulch is found to be economically and agronomically feasible under drip irrigation system [71]. Potato yields were highest for SDI method compared to surface and subsurface drip irrigation regimes with saline water, although no significant differences were observed with the DI irrigation [77].

Generally authors tried to focus their concentration on water saving crop production which is technically and economically sustainable. Darouich et al. [52] found that drip irrigation save 28 to 35% water compared surface irrigation. Moreover, drip irrigation systems offered increased water productivity (0.61 kg/ m^3) than that of surface irrigation (0.43 kg/ m^3). Singandhupe et al. [67], in their study obtained 3.7 to 12.5 percent higher fruit yield with 31 to 37 percent saving of water in the drip system compare to furrow irrigation. Therefore, this study show the overall drip irrigation perspectives on the basis of system application, methods and techniques in different circumstances on varieties of outcomes including yield and profit. Over the last few decades' agriculture have huge changes and lead to significant increase in food security through higher food production [100]. International Commission on Irrigation and Drainage (ICID) published a report on irrigation of 45 countries including India, China, Spain, USA, Italy, Korea, Brazil, South Africa, Iran, Mexico and Middle Eastern countries where the largest areas were under drip irrigation systems [106,107]. According to FAO Aquastat website reported from 2008-2012, among the 199 countries of the world only 15 countries practiced drip irrigation (localized irrigation) crop production which has now increased to 85 countries [107,108]. The global Aquastat data of Fig. 4 further disclosed that, around 86% of the area are now equipped with surface, 11% with sprinkler and 3% with drip irrigation [109].

3.4 Alternative Water Use in Drip Irrigation

Scarcity of fresh water and high water salinity in arid and semiarid region throughout the world is chronic problem [41]. Therefore, utilization of alternative water for irrigation is a necessity for future agriculture. At present, competition of fresh water in the development of urbanization, industry, recreation, and agriculture causes the decline of fresh water for irrigation [110]. Huge amount of saline water resources in the world [111] and reclaimed municipal wastewater [112] may be good alternative for irrigation. Accordingly, it is necessary and feasible to use saline [113] and reclaimed water [92] for agricultural irrigation, if appropriate crops, soil, and water managements are applied. Over the long period the characteristic of low and high steady flow rate in drip irrigation can maintain soil matric potential that compensate to decrease osmotic potential of saline water that can help crop growth smoothly [104,114,115]. In case of using reclaimed water, Sacksa and Bernsteinb [92] suggested that, it can be applied today primarily for orchards and field crops cultivation but not for vegetables which is usually eaten as raw because of human health concern. The authors found that the effluents contained higher levels of EC, pH, Na and Cl, N, P, K, microelements, and heavy metals in reclaimed water than that of the potable water. However, it obtained similar melon yield quantity and quality by different treatments. Kang et al. [104] found that drip irrigation with saline water (<10.9 dS/m) not affect the emergence of waxy maize. About 1 dS/m increasing in salinity decreased about 0.4-3.3% ear yield. Rajak et al. [54] studied comparative effects of drip and furrow irrigation on the yield and water productivity of cotton with saline and waterlogged vertisol that obtained maximum yield 1.78 Mg/ha. In that case drip irrigation applied at 1.2 ET showed improved water productivity than furrow irrigation due to formation of salt with moisture regimes. Field experiment results showed that soil moisture and salinity increased due to increasing N application rate and salinity respectively [41]. Kahlaoui et al. [69] conducted field experiment and compare the effects of saline water on tomato in nutrition and foliar aspect under surface (DI) subsurface drip irrigation (SDI). In which leaf area, chlorophyll content and mineral composition of leaf, petioles, stems and roots were significantly affected by different treatments.

3.5 Drip Irrigation Model Practice

Integrated modernization in irrigation will require both 'hardware' and 'software' investments. Drip irrigation system belongs to modernization include a range of 'software' improvements such as scheme management, on-farm water management practices, combined water and soil fertility management, drainage water management, and integrated approaches to combat drought, salinity and floods [9]. An artificial neural network model (ANN, mathematical construct) was established by Li et al. [116] for simulation of nitrate distribution in drip irrigation including adsorption, transformation, convection, and dispersion. The authors used input parameters of initial soil moisture content, initial nitrate concentration, irrigation discharge rate and applied volume, fertilizer (NH4NO3) concentration and final soil moisture content. They found that there is a good relation (r^2 = 0.83) between the model estimated nitrate concentration of soil and laboratory measured soil. Arshad et al. [117,118] designed for analyzing the reliability, efficiency, dependability and harmony of the proposed drip irrigation system and analyzed drip irrigation uniformity using IRRIPRO software. Simulation used in designing and planning viable drip irrigation systems achieved high coefficient. The distribution uniformity indicated this irrigation system. In comparison to experimental and simulated results the application of uniformity was satisfactory. Selim et al. [119] accomplished simulation of soil water and salinity distribution under surface drip irrigation by HYDRUS-2D/3D

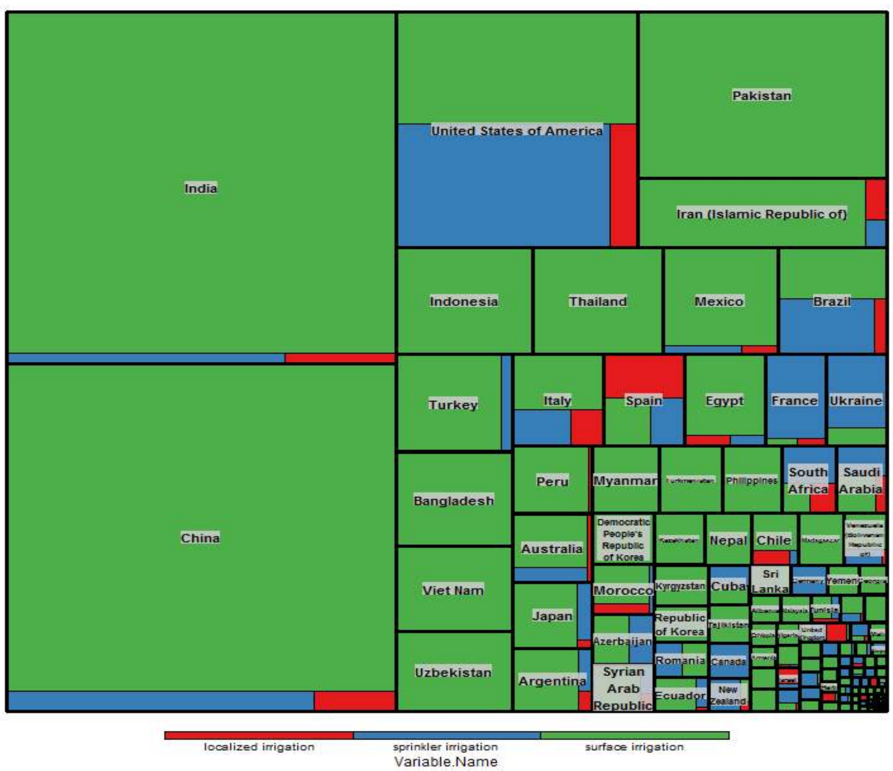

Fig. 4. Distribution of area equipped for different irrigation by technology within each country and globally (Source: [109])

model using tomato crop and found the effect of irrigation treatment on wetting patterns was differed with initial soil moisture content. Phogat et al. [120] used HYDRUS-2D model to evaluate seasonal water balance and salinity distribution in soil under advance fertigation system of two horticultural crops. The Similar comparison were found between measured and model salinity (ECsw) and RMSE ranged between 0.09 to 0.93 dSm^{-1} that was sound within the acceptable limit. MIRRIG simulation model indicates that drip irrigation can lead 28 to 35% water saving compared to improved graded furrows [52].

4. SUMMARY AND CONCLUSION

This study illustrates that drip irrigation system spreading enormously worldwide due to increasing demand of water for agriculture, industries, domestic and others uses. According to the views of ‘one drop more crops’ this study took an attempt to review of the contemporary perspectives of drip irrigation with an evidence of water saving crop production using worldwide available information. The challenges of global warming and climate change will affect the balance between water demand and water availability necessarily has to face near future generation especially people lives in water-stressed countries. Aquifer water tables and river levels are declining with stage in many parts of the world due to face the agriculture and human water use. Day-by-day agricultural land under irrigation increases because of distribution of rainfall does not coincide with the schedule of crop water requirements. Globally, various types of crops were practiced under drip irrigation comparing with surface and sprinkler irrigation. Drip irrigation is still increasing in period as some researchers introduce low-pressure, low-cost drip system which can easily provide advantage to the medium and small farmers. Currently, saline and waste reclaimed water use is increasing for achieving the requirements of fresh water as an alternative water sources. In comparison with other irrigation, drip system would allow for an intensification of agriculture (economic development), more efficient use of water and contribute to poverty alleviation (social development). Thus, the review clearly make sense that nowadays drip irrigation crop practices are increasing all over the globe and it became the most demanding issue for crop production due to high efficiency water use in water scares area as well as arid and semi-arid region. It is, therefore, recommended that, surface water irrigation will necessarily decrease due to low efficiency and considerable conveyance losses, though nearly half of the world’s population is living under water poverty level.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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