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Strategies for enhancing water productivity in horticultural crops

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Abstract

Water is the most critical input for horticultural productivity, and efficient use of water is critical for the development of sustainable horticulture. The efficiency of irrigation water use continues to be low with adverse environmental repercussion. Increasing water- use efficiency through improved irrigation systems as an alternative or a complement to physically enhanced water supplies is an important issue in water resource management. Micro-irrigation has emerged as an appropriate water saving techniques for all wide spaced high value crops in water scarce, undulated and sandy areas of hot arid ecosystem. This paper deals with the present status of micro-irrigation research, economics of different micro-irrigation systems and the need for affordable and low cost micro-irrigation systems. Future research on micro-irrigation is needed (i) to improve the performance of drip system, and (ii) to include fertigation study. The various studies revealed that the productivity of horticultural crops can be enhanced to the tune of about 60-70 percent by adopting micro-irrigation.

Key words : *Water productivity, microirrigation, water management and horticultural crops*

Introduction

Agriculture is the largest single user of water, with about 75% of the world's freshwater being currently used for irrigation. In some countries, irrigation accounts for as much as 90% of the total amount of water available (FAO, 2003, 2005). Given that water productivity in agriculture continues to be low and that improvements are only being made very slowly, and that freshwater has always been an integral component of food production, it is obvious that huge amounts of water will be required to produce enough food for the future population of the world. The situation is more alarming in arid and semi-arid regions where the water is very scarce, rainfall is low and erratic and deep groundwater level with low recharge capacity perennial water storage structures. Due to these factors, majority of the areas remain dry and fallow which limits agricultural production.

Such areas can be fruitfully utilized for commercial cultivation of horticultural crops because majority of horticultural crops are perennial in nature, widely spaced, low water requirement in comparison to field crops, deep and extensive root system capable of extracting water from deeper layers, large canopy to harvest optimum natural resources better and high yielding. In addition to above, the irrigation water requirement of horticultural crops differs with respect age, growth stages and season. Because of this the irrigation scheduling of these crops can be planned in advance so that available water can be optimally utilized.

Since the crops are widely spaced a large interspaced area remains uncultivated hence there is need to develop technologies to provide water at the site of consumption so that various losses such as evaporative, seepage, conveyance and water required to wet interspaced area can be avoided which will save the large amount of water that can be utilized to irrigate additional area which otherwise remains barren. This will improve water productivity in arid and semiarid regions by producing more biomass with the same of water giving through traditional method. Water is fundamental requirement in development of horticulture and hence horticulture relies on irrigation, whereby responsible water use is the key to the success of horticulture. Here excess and scarcity of water often cause considerable losses both in quantity and quality in fruit production. Therefore, optimum water use practices considering the water requirement and application techniques must be followed.

Due to increased water scarcity, the irrigated area is unlikely to expand in the dry land region of the country. Therefore, life saving irrigation, supplemental irrigation, the combination of dry land farming irrigation at critical growth stages, and regulated deficit irrigation, would be an ideal choice for improving horticultural crop yields in this region. Good irrigation scheduling requires the timing of irrigation, crop water requirement and the amount of water applied to match actual field conditions. This needs

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information on soil moisture status (whether in terms of water content or water potential) at the time of irrigation and, when using irrigation, close cooperation among farmers to be effective. The choice of irrigation scheduling method also depends to a large degree on the objectives of the irrigator and the irrigation system available. The more sophisticated scheduling methods generally require higher precision application systems; nevertheless even less sophisticated systems such as flood irrigation scheduling can benefit from improvement in irrigation scheduling. The pressures to improve irrigation use efficiency and to use irrigation for precise control of vegetative growth, as in regulated deficit irrigation (RDI), both imply a requirement for increased precision in irrigation control, maintaining the soil moisture status within fine bands to achieve specific objectives in crop management (Jones, 2004).

Studies have shown that following strategies can be adopted to enhance the water productivity through horticultural crops

1. Use of water conservation techniques such as mulching, pitcher irrigation, double walled pot, use of soil amendments, water absorbing polymer, etc.
2. Use of pressurized irrigation, tank irrigation, *ex-situ* and *in-situ* water harvesting methods can be used
3. Application of water at critical times in relation to growth and development stages of fruit and vegetable crops and varying agro climatic conditions.

Method of Irrigation

Different irrigation methods of irrigation have been used in orchards depending on water availability, topography, fruit species, age of tree, intercrops, etc.

Check basin

For irrigating different fruit crops, check basin system has been used. The size of basin depends on the plant age and is kept small in the beginning. Singh *et al* (1961) suggested that young citrus trees upto 5 years should be irrigated by basin system. Irrigating water should not touch the main trunk, otherwise there are chances of disease infection. Heaping soil around the tree trunk is good practice to avoid moisture contact with scion. The basin should, therefore, be made sloping downwards from the tree trunk

Almost 60-80 per cent of root activity in citrus is confined to the top 60 cm profile and the roots spread beyond the canopy of the trees. Aiyappa *et al.* (1970) reported that furrow irrigation is wasteful and ineffective irrigation system. For young plants of sapota, small basins are made which are increased in the size as the tree grows in age. In coastal Gujarat, 0.5 m high mounds are made around the trees to save them from bending by wind action and to conserve soil moisture (Singh, 1969).

Ring basin

Young mango trees are best irrigated by modified ring method (Singh, 1969). When intercrops are taken, the basins of trees are connected in a series to make them independent of the intercrop (IIHR, 1985b). Ring and furrows or basin methods are generally adopted to irrigate the bearing tree. Irrigation water should not touch the trunk of papaya plants therefore, ring method of irrigation is considered best in which basins are kept sloping downwards from the trunks (Singh, 1978).

Pitcher irrigation

The technique is very useful to establish young plants in sandy wasteland areas having little or no irrigation facility (Pareek, 1987). Small pitcher of about 3 litre capacity having a hole at bottom fitted with a wick is buried alongside a newly planted sapling. The pot is occasionally filled with water and its mouth is kept closed. In a grown up orchard, one or two or three pitchers around a tree, depending on its age and spread can be buried. In a 16-year-old Mosambi orchard, two 30-liter pitchers per tree gave satisfactory growth (Patil *et al.*, 1987).

Rainwater harvesting

The rainwater harvesting system for agriculture in arid and semi-arid areas may follow have following components or phases depending upon the location specific situation:-

1. Direct rainwater conservation
2. *In-situ* moisture conservation
3. Water harvesting (runoff collection and storage)

Direct rainwater conservation :

The approach to rainwater harvesting and conservation are through agronomic and engineering measures. This will not only harvest, conserve water but also prevent soil erosion particularly in semi-arid tract. The measures are contour framing, strip cropping, farming terraces, cover crops, off season tillage in light soils, deep tillage in hard pan areas, summer fallow, mulching, providing vegetative barrier on contour in the land. Deep tillage helps in increasing water intake in soils having textural profiles or hardpan. Surface mulch in post rainy season reduces evaporation resulting higher crop yields. The engineering measures adopted differ from place to place with reference to slope, soil type and intensity and total rain etc. Depending upon the parameters, the methods followed are – the contour trenching, contour stone walls, staggered trenching, constructing temporary and permanent check dams, gully plugging, contour bunding compartmental bunding, land leveling.

In-situ moisture conservation :

In most of the arid and semi-arid tropics, the rainfall is erratic and falls within a short time. The moisture may not be available to the crop at the critical stage of its growth. In situ moisture conservation can help in retaining soil moisture regimes for a longer duration. For tree crops, Micro-catchments, saucer basin/semi-circular bunds and catch pits can be introduced. It is necessary to adopt the *in-situ* moisture conservation techniques in addition to the large-scale soil and moisture conservation and water harvesting measures in the watershed. By adopting these measures, it is possible to increase the survival percentage in tree crops may be even 90-95 percent. The technique is most effective since the deep-rooted perennial fruit trees can draw the runoff water concentrated even in the deep soil profiles from the few rainfall incidences. However, the runoff generation depends upon several characteristics of the catchments e.g. size, slope, soil structure, covers surface characteristics such as compaction, smoothness, vegetation, etc., besides rainfall pattern (intensity and duration etc.) of the region. Therefore, catchments size, its slope and other characteristics would vary in different regions.

Table 1. Catchments area per tree and plant population per hectare with different slopes of sandy catchments

Fruit	Canopy area (m^2)	Runoff supplement (mm)	Catchment's slope (%)	Catchment's area (m^2)	Area per tree (m^2)	Population per ha
Ber	36	300	0.5	100	136	74
			5.0	75	111	90
			10.0	60	96	104
Pomegranate	20	800	0.5	148	168	60
			5.0	111	131	76
			10.0	89	109	92
Guava	56	800	0.5	415	471	21
			5.0	311	367	27
			10.0	249	305	33
Fig	56	800	0.5	415	471	21
			5.0	311	367	27
			10.0	249	305	33
Aonla	56	500	0.5	259	375	32
			5.0	194	250	40
			10.0	156	212	47
Sour Lime	36	1000	0.5	333	369	27
			5.0	250	286	35
			10.0	200	236	42
Custard apple	20	300	0.5	56	76	132
			5.0	42	62	161
			10.0	33	53	189

The watersheds are divided into micro catchments considered optimum either for a tree or a group of trees, arranged in a row or other patterns suited to the location. In nearly flat areas, catchments could be provided on two sides of a tree row or around each tree. The optimum catchments are worked out considering water requirement and root architecture of the fruit specie, on one hand, and the expected water input through rainfall and runoff, on the other. Study gave estimates of the catchments area (Table 1) required per tree and tree per hectare of different fruits for growing in sandy catchments. Using the formula, A= TS/RC, where A is catchments area per tree in m^2, T is canopy are of the tree in m^2, S is runoff supplement required in mm per tree to meet the rainfall deficit, R is average annual rainfall in mm and C is runoff coefficient of the soil.

Ber plantation has been raised with in situ runoff concentration system under hot arid climatic conditions of North West India. The fruit yield in Gola and Seb cultivars of ber increased with increase in degree of slope and decreased with length of run as a result of increase in runoff and moisture storage in a 3 m soil profile. The highest fruit yields were obtained when 0.5 and 5 percent respectively had 8.5 and 7 m length of run and 72 and 54 m^2 catchments area per tree giving 2 and 1.5 contributing per planted area ratios.

Water harvesting (Runoff collection and storage):

Water harvesting refers to collecting the excess runoff from rain on the farm in ponds and utilizing it later for both domestic and agricultural uses. The systems either concentrate water into a storage reservoir or apply water directly to the soil in the cropped area. Both types of systems can vary in scale from a few hectares benefiting a single farmer to a few hundred hectares (watershed) saving a larger group of people. Rainwater harvesting is achieved either (i) *in-situ* through terraces, trenching, conservation tillage, mulching, contour barrier and run-off controlling crops, or (ii) *ex-situ* collection of run off in devices such as tanks, ponds, reservoirs and dams. Rainwater harvesting through tanks, ponds and reservoirs has been practiced traditionally in India for a long time. Several indigenous methods based on local wisdom were devised to store the rainwater in dry Rajasthan (in the form of nadi, tanka, khadin and percolation tanks); bhandharas in Maharashtra; bandhis in MP and UP; and ahars in Bihar (Samara *et al.*, 2002). Due to the limited volume of water that can be stored in these traditional structures, the technology is usually used together with other water-saving measures such as sowing the plants with a small amount of water at the time of planting, plastic mulching, root zone drip irrigation, sprinkler irrigation and under mulch irrigation. Especially the micro-irrigation systems like drip and sprinkler economize both water and fertilizers. These systems could be popularized to increase the productivity of limited rainwater. And therefore, the stored water can be successfully used in the production of cash crops like watermelon, greenhouse vegetables and fruit crops; thereby it will also provide an even greater economic benefit to the framer. The use of harvested rainwater for supplementary irrigation in the stress period particularly to trees and crops caused tremendous increase in the yield of several crops in different regions (Venkateswarlu, 1981). Most common tankas are 2.5 to 3 m deep having storage capacity of 10 to 21 m^3. More recently, tankas of 50 m^3 capacity have successfully been popularized for meeting drinking demands as well as establishing horticultural plantations in 1 ha area (Gupta *et al.*, 1998). Studies conducted at Jhanwater watershed near Jodhpur, harvested rainwater from a farm pond of 271 m3 capacity was used to grow *ber* plantation and subsequently to provide supplemental irrigation, which resulted in increased fruit yield (8 q ha^{-1}) with 1.67 : 1 benefit : cost ratio (Narain and Goyal, 2005). Some more studies also revealed that supplemental irrigation from tankas in loamy sand soils had increased fruit yield by 46-124% of ber (*Ziziphus mauritiana*) and 70-199% of pomegranate.

Thus water harvesting and its utilization have become a strategic measure for social and economic development in this region, providing an effective means of alleviating poverty and allowing a breakthrough in dry land farming/ horticulture.

Water management for harvested water :

Development of dry land/arid horticulture as understood does not mean that no irrigation development altogether takes place as part of this programme. Giving one or two irrigation to a crop at certain critical stages of water stress during its growth cycle is now recommended in dry land/arid horticulture. To make such irrigation possible, dry land horticulture development includes watershed development programme. The irrigation is provided once/twice in the crop season from the meager water resource such as farm pond/wells giving less water.

Soil management

The loss of soil moisture through evaporation, especially in arid regions can amount to 50% or more of total precipitation (Hillel, 1998). This much evaporation losses can be reduced by modifying the albedo of the sandy soil through mulching. Covering or mulching the soil surface with vapour barriers or with reflecting materials can reduce the intensity with which external factors, such as radiation and wind, act on the surface (Hanks, 1992). Reductions in direct evaporation of water from the soil surface could improve the efficiency with which water is used. For decades, the farmers have been trying to use various materials such as dry leaf, paddy straw, paddy husk, jowar trash, saw dust, dry grass, dry sugarcane leaves, dry coconut leaves, coconut husk etc. for reducing water evaporation losses. Checking weed growth, and create a micro-climate which regulates soil temperature, humidity and microbial activity. However, all these materials, though beneficial, were found to have inherent weaknesses and cost disadvantage. This lead to the use of plastics films as mulches, which are today the most preferred material. At present, around 10,000 ha area is under plastics mulching in India (Choudhary and Kumar, 2005). The importance of synthetic mulches especially in vegetable crops has been proved beneficial in increasing the soil moisture conservation, moderating the soil temperature and eliminating the weed growth and hence increases the crop yield. LDPE and LLDPE plastic films are commonly used for mulching. LLDPE black colour mulch films are more popular owing to the twin properties of possible down-gauging and better puncture resistance. Down-gauging leads to the availability of thinner films at lower cost and the puncture resistance and opacity check the weed growth under the film.

Comparative performance of synthetic and organic mulches with control in brinjal (*Solanum melongena* L.) grown in aonla based multistory cropping system was studied by Awasthi *et al.* (2006) under hot arid ecosystem of Bikaner. The results revealed that synthetic mulches (black and white polyethylene of 75 micron thickness) conserved 46 to 50 more moisture in comparison to control. The effect of synthetic mulches (77-84%) was more pronounced on fruit yield than the organic mulches (58-60%) compared with control. In one study, it was also reported that straw mulching increased the mean yield of tomato and okra by 107 and 388%, respectively.

Table 2. Area covered under drip irrigation in India

S. No.	State	Hectare
1	Maharashtra	46000
2	Karnataka	31500
3	Tamil Nadu	21000
4	Andhra Pradesh	15000
5	Kerela	4700
6	Gujarat	4500
7	Madhya Pradesh	2300
8	Orissa	1750
9	Rajasthan	1700
10	Haryana	1400
11	Punjab	1100
12	Uttar Pradesh	700
13	Goa	300
14	Nagaland	250
15	Manipur	200
16	Sikkim	100
17	Others	2500

Table 3. Fruit crop-wise area under drip irrigation in India

S. No.	Crop	Hectare
1	Coconut	36000
2	Grapes	36000
3	Banana	22500
4	Citrus	21000
5	Mango	19500
6	Pomegranate	17000
7	Sapota	6000
8	Ber	6000
9	Guava	4500
10	Arecanut	4500

Micro Irrigation

The growth of micro irrigation has gained momentum in the last ten years. From a mere of 1500 hectares in 1985, the area under drip irrigation has gone to over 3.0 lakh hectares at present (Singh *et al.*, 2000). Coverage of total and fruit crop area under drip irrigation at national level is presented in Table 2 and Table 3.

Drip irrigation or more broadly known as micro irrigation is mainly suited for orchard and plantation crops where it saves 30-70 per cent irrigation water and increase yield by 25-80 per cent. Evidences from drip irrigation trials have clearly indicated the advantages like water saving, higher productivity, limited weed growth, better management of assets, off season maturity, better fruit quality and reduced

Table 4. Relative performance of crops with drip irrigation in comparison with that of traditional irrigation methods

Crop	Location	Yield (q ha^{-1})		Irrigation water (cm)		WUE (Q ha^{-1} cm^{-1})		Advantages of drip irrigation	
		Surface	Drip	Surface	Drip	Surface	Drip	Saving of water (%)	Increase in yield (%)
ASH gourd	Jodhpur	108	120	84	74	1.3	1.6	12	10
Beet	Coimbatore	5.7	8.9	86	18	0.07	0.5	79.1	36
Bottle gourd	Jodhpur	380	558	84	74	4.5	7.5	12	31.9
Bitter gourd	Chalakudy	32	43	76	33	0.42	1.3	56.6	25.6
Brinjal	Akola	91.0	148.0	168.0	64.0	0.55	2.3	62.0	38.5
	Delhi	280.0	33.8	45.0	35.0	6.2	9.7	22.2	17.2
	NCPA	280.0	320.0	90.0	42.0	3.11	7.6	53.3	12.5
	Pune	225.0	245.0	78.0	51.0	2.9	4.8	34.6	8.2
	Rahuri	280.0	280.0	90.0	42.0	3.11	6.7	53.3	0.0
Broccoli	Delhi	140	195.0	70.0	60.0	2.0	3.25	14.3	28.2
Cauliflower	Akola	83.0	116.0	39.0	26.0	2.1.0	4.5	33.3	28.4
Chilly	Pantnagar	171.0	274.0	27.0	18.0	6.3.0	15.2	33.3	37.6
Cucumber	NCPA	42.3	60.9	109.0	41.7	0.30	1.5	61.7	30.5
Ladyfinger	Pune	155.0	225.0	54.0	24.0	2.9	9.4	55.6	31.1
	Coimbatore	100.0	113.1	53.5	8.6	1.87	13.2	84.0	11.6
	Delhi	360.0	480.0	42.0	26.0	8.6	18.5	38.1	25.0
	Rahuri	189.0	203.0	219.0	113.0	0.86	1.8	48.4	7.0
Onion	Delhi	284.0	342.0	52.0	26.0	5.5	13.2	50.0	17.0
	Hisar	93.0	112.0	50.0	45.0	1.6	2.5	25.0	17.0
Potato	Delhi	172.0	291.0	60.0	27.5	2.9	10.6	54.2	41.0
	Hisar	235.7	344.2	20.0	20.0	11.8	17.2	0.0	31.5
	Parbhani	334.0	480.0	30.0	22.0	11.1	21.8	26.7	30.4
Raddish	Coimbatore	10.5	11.9	46.0	11.0	0,23	1.1	76.1	11.8
Sugarbeet	Hisar	418	489	50.0	37.0	8.4	13.2	26.0	14.5
Sweet potato	Coimbatore	42.4	58.9	63.0	23.0	0.67	2.4	60.3	28.0
Tomato	Akola	45.0	58.0	102.0	77.0	0.44	0.75	24.5	22.4
	Coimbatore	6108	88.7	49.8	10.7	1.24	8.28	78.5	30.3
	Delhi	257.0	396.0	47.0	25.0	5.5	15.8	46.8	35.1
	Ncpa	320.0	480.0	30.0	19.0	10.7	25.3	36.7	33.3
	Pantnagar	104.0	137.0	22.0	14.0	4.7	9.8	36.4	24.1
	Parbhani	320/0	480.0	32.4	22.2	9.9	21.6	31.5	33.3
	Pune	292.0	413.o	31.0	20.0	9.4	20.7	35.5	20.3
	Rahuri	16.4	17.2	29.7	20.8	0.6	0.82	30.0	4.7
	Udaipur	144.0	175.0	41.0	28.0	3.5	6.3	31.7	17.7
Banana	Hawanisagar	277.0	329.0	186.0	172.0	1.5	1.9	7.5	15.8
	Kharagpur	290.0	400.0	106.0	106.0	2.74	3.8	0.0	27.5
	Ncpa	575.0	875.0	176.0	97.0	3.27	9.0	45.0	34.3
Ber	Belvatgi	13.7 kg/tree	18.0 kg/tree	15.4 m³/plant	12.5 m³/plant	0.9	1.4	18.8	23.9
Grapes	Dharwad	101.0	101.0	53.0	28.0	1.91	3.6	47.2	0.0
	Ncpa	264.0	325.0	53.0	28.0	5.0	11.6	47.2	18.8
Guava	Allahabad	0.16 /plant	0.22 /plant	6.4 m³/plant	5.21 m³/plant	0.03	0.04	18.6	27.3
Kinnow	Delhi	68.0	98.0	22.1	17.3	3.1	5.7	21.7	30.6
Lemon	Delhi	15.0	27.0	23.0	17.5	0.65	1.54	23.9	44.4
Papaya	Coimbatore	130.0	230.0	228.0	73.0	0.6	3.20	685.0	43.5
	kalyani	312.0	383.0	24.0	11.0	13.0	34.8	54.2	18.5
Pomegranate	Belvatgi	7.4	14.4	10.7	8.7	0.7	1.7	18.7	48.6
	Delhi	34.0	67.0	21.0	16.0	1,62	4.2	23.8	49.3
	Hyderabad	15.0	37.0	183.0	178.0	0.08	0.21	2.7	59.5
Water Melon	Jodhpur	294.6	882.0	80.0	80.0	3.7	11.0	0.0	66.6
	Pune	82.1	504.0	72.0	25.0	5.9	20.2	65.3	16.3

incidence of insects and pests and disease (Sivanappan *et al.*, 1978).

Mis-management of available irrigation water throughout the tree growth is one of the reasons for low productivity in fruit crops. Thus, the available water must be used effectively and efficiently for the fruit crops so as to increase their productivity.

Magar and Firke (1994) reported the results in respect of the quantity of water applied, water saving and water use efficiency compared to conventional method of irrigation in different fruit crops. The relative performances of crops with drip irrigation in comparison with that of traditional irrigation method studied at various locations and their results were given in Table 4.

Banana (*Musa* Spp.)

Banana is one of the important fruit crops of the country, which consume huge quantity of water (Rajput and Sharma, 1998). Sivanappan *et al.* (1977) reported better performance of banana under drip irrigation compared to surface irrigation method. Tiwary *et al.* (2000) reported the increase in yield and net seasonal income of banana could be obtained by 60.2% and 61%, respectively, using drip irrigation with plastic mulch as compared to conventional basin irrigation. Shivanappan (2000) reported that in banana, drip irrigation increased the fruit yield by 52% and saved the 45% irrigation water over conventional system. Srinivas and Hedge (1990) reported that increasing evaporation replenishment upto 60% increase the yield significantly. Srinivas and Singh (1992) demonstrated that drip irrigation saved water to the tune of 45% in banana. In semi-arid conditions, about 10% increases in yield and 50% water saving has been reported (Anonymous, 1987). At NRC for Banana, Trichy, in cv. Poovan, it was observed that maximum number of fruits per bunch and bunch weights were recorded with higher level of irrigation and nitrogen fertigation.

Table 5. Effect of methods of irrigation on growth and yield of Ganesh pomegranate

Method	Water used Litres	Tree height (m)	Stem diameter (m)	Fruit yield (q/ha)	WUE Q/ha cm
Check basin					
0.6 IW/CPE	4800	2.35	3.78	40.6	0.82
0.8 IW/CPE	6600	2.56	4.02	47.5	0.69
Trickle					
Daily					
20% WA	3580	2.16	3.79	52.5	1.25
30% WA	5322	2.44	4.02	55.9	0.72
Alternate day					
20% WA	3580	2.30	3.84	48.6	1.16
30% WA	5322	2.24	4.01	57.3	0.92

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Pomegranate (*Punica granatum*)

Sivanappan and Natrajan (1976) reported that drip irrigation system may prove to be economic and water saving for pomegranate orchard. Bangal *et al.*, (1987) reported that pomegranate crop requires irrigation from January to July for fruit harvest and drip system with mulch saved about 78% irrigation water over check basin system. Pampattiwar *et al.* (1993) found that drip irrigation method, applying water equivalent to 20 per cent area is superior method of water application over surface method and average annual irrigation requirement of pomegranate through drip method is 20cm. Varshney *et al.* (1993) reported that in cv. Ganesh, drip irrigation, in addition to water use efficiency, marketable produce increased as no cracking was observed. In arid conditions of western Rajasthan, Sharma *et al.* (2001) found that in pomegranate crop, drip irrigation system saved 25% irrigation water and increase the yield by 87.5% over pipe irrigation system. Trickle irrigation on alternate day with 30% wetted area gave maximum fruit yield (57.3 q ha^{-1}) of Ganesh cultivar of pomegranate (Anon., 1987). Kulkarni (1988) reported that water use efficiency was maximum (3.38 q ha^{-1} cm^{-1}) in 20% wetted area daily treatment followed by 20% wetted area drip irrigation alternate day (3.32 q ha^{-1} cm^{-1}). In fertigation trial, it was observed that irrigation @ 20 per cent AWC along with 125 percent level of fertilizer dose have given maximum fruit yield (Anonymous, 2000) The data in Table 5 revealed that although tree growth was not affected, the fruit yield and water use efficiency were considerably increased by drip irrigation in *cv.* Ganesh pomegranate at Rahuri in Maharashtra.

Ber (*Ziziphus mauritiana*)

In northern India most crucial period of irrigation in ber is during the commencement of new flush and fruit development and which comes respectively between June to July and September to January. Considering the season and soil conditions, ber plants requires about 20-35 litres water per day. Singh *et al.* (2000) reported that in drip irrigation system saved about 19% irrigation water and increased the fruit yield by 24% over surface irrigation system. Sharma *et al.* (2002) reported that in extreme arid conditions, drip fertigation saved the 25% irrigation water and increased fruit yield (87.5%) over pipe irrigation system. The maximum water use efficiency (21.05 g l^{-1}) in ber was recorded when plants were irrigated at 0.75 CPE through drip (Anonymous, 2002).

Aonla (Emblica officinalis)

Aonla is a promising fruit crop for arid and saline wastelands (Supe, 1995). In this crop, optimum availability of soil moisture can enhance the quality of the fruit. Under North Indian conditions plant growth occurs during March and April and August to November, therefore, assured irrigation to this crop is very much essential. Considering the critical stage of growth and fruit development, 160-180 days of irrigation through drip is essential during this period. Irrigation regimes and frequencies influence the growth characters of plants. Maximum plant height, girth and spread were recorded with 60% CPE level of irrigation at 3 days interval. Shukla and Pathak (1996) reported that irrigation through drip with plastic mulch increased the fruit yield and plant growth in saline-sodic soils.

Mango (*Mangifera indica*)

Experiment conducted at Rahuri indicated that micro irrigation through drip could save 50 pe rcent of irrigation water (Desai, 1995). At CISH, Lucknow, in mango cv. Dashehari, the results revealed that the irrigation to the tune of 60 per cent open pan evaporation combined with fertigation (half dose of N) has recorded highest yield (83.10 kg/tree) in young orchard as compared to control (56.24 kg/tree) (Anonymous, 2000).

Guava (*Psidium gujava*)

Singh *et al*. (2000) reported that drip irrigation saved about 19 per cent irrigation water and increased the fruit yield to the level of 27 per cent over surface irrigation method. In cv. Sardar, the results revealed that the irrigation at 60 per cent replenishment of evaporation along with 50 percent nitrogen fertigation had produced maximum yield (75.11 kg/tree) followed by 40 and 20 per cent replenishment of evaporation (62.87 and 39.06 kg/tree), respectively (Anonymous, 2000)

Citrus

In North India, weekly irrigations are provided during March-June and fortnightly during November-February (Ghosh, 1985). The critical period for irrigating citrus trees is during summer when frequent light irrigations help to lower soil temperature and to raise humidity (Singh, 1969). During spring and summer months, soils may somewhat dry out but wilting should never be allowed to occur. Even in high rainfall areas, water stress may occur in summer. During summer (May-June), irrigation should be done at weekly interval (Singh, 1978). In Nagpur mandarin, water stress of 30 to 40 days duration in December-January, followed by scheduling of irrigation after flowering at 50 to 75 per cent depletion of available moisture, in clay loam soil under hot, dry climatic conditions, resulted in optimum growth and fruit yield (Chinappa *et al.*, 1977).

Date Palm

The date orchards must be regularly supplied with irrigation water during the flowering and fruit development period i.e., during February to August in North West India. To maintain vigour, less frequent irrigations are required during rest of the year. Date palm can withstand in high saline irrigation water.

Grape

In North India, vines need regular irrigation from March to June during the growth and fruiting period. No watering is normally done during the dormancy period in water. However, one or two irrigations may be required if there is prolonged dry spell. The first irrigation is applied after pruning and the second after 25-30 days to ensure good fruit set. Later on, irrigation is applied at 7-10 days interval until fruit maturity, depending on growth phase, temperature and other environmental factors. Withholding watering during flowering results in high bunch and berry weight and yield but lack of irrigation at fruit set and moisture stress during berry development reduces fruit size and yield. Frequent heavy irrigations before fruit set encourages vegetative growth at the cost of fruiting. Irrigation is normally stopped when berries have started maturing. Excessive irrigation at this stage would cause splitting and rotting of berries and reduction in fruit quality. Prolonged flooding also destroys the root system. However, the vines should not suffer of water stress. In North India, up to 9 irrigations from March to the ripening of fruits in June are given. In Western India, 6 irrigations are given during the fruiting season from October to March and 3 from April till the break of monsoon (Singh, 1969). In South India, vines are irrigated weekly from the time of summer pruning until the onset of monsoon and thereafter at 10-12 days interval until winter pruning (IIHR, 1986). Too frequent irrigations are avoided after summer pruning as it adversely affects flower initiation by promoting vegetative growth. Similarly, too frequent irrigations from flower opening to peak stage of berries should also be avoided as they aggravate the problem of downy mildew disease.

Some of the specific research strategies to enhance the water productivity in horticultural crops would be as under :

a) The water requirements of the field crops under surface irrigation are reasonably well known. However, the water requirement of orchard crops under different agro-climatic zones of the country needs to be worked out.

b) The moisture distribution pattern consisting of wetting zones in the horizontal and vertical directions would differ from soil to soil according to infiltration characteristics and other factors. It is essential that the wetting pattern have to be studied properly for different crop-soil combinations to evolve the requirement of wetting at different stages for attaining the higher water efficiency under micro-irrigation.

c) The irrigation frequency and proper scheduling need to be established for different crops under varied soil and climatic conditions.

d) A scientific basis for replenishing moisture in root zone at different stages of tree growth has to be standardized under micro-irrigation system.

e) The application method, fertilizer quantity, frequency and mode of applications should be determined for different crops under different soil and climatic conditions of the country.

f) It is necessary to evolve a package of practices to use saline water for tolerant crops through micro-irrigation system in salt affected areas of the country.

g) Experimental studies should be carried for exploring the feasibility of micro-irrigation system in other areas.

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