Drip Irrigation

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Source: Univ. Hawaii Vegetable Crops Update Newsletter, Vol. 4, No. 2 (March 1994)
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Drip irrigation technology has gone a long way since it was first developed in England in the 1940s. Widespread use of this technology began in the 1960s after polyethylene plastics were used to make the drip tubes. Drip irrigation is especially appropriate for the production of capital intensive crops such as vegetables, fruits, and ornamentals. However the use of drip irrigation requires a high initial capital investment as well as greater management skills than for more conventional irrigation systems. The incorporation of drip irrigation with plastic mulch culture of vegetables result in greater water and fertilizer use efficiency, and has resulted in increased yields of muskmelon, cucumber, eggplant, pepper, squash, tomato, watermelon, among other vegetable crops. For example, bell pepper yields in Puerto Rico were 12 MT/Acre with drip and no mulch, vs. 19 MT/Acre with drip and plastic mulch culture (Crespo-Ruiz et al., 1988). Irrigation efficiency with drip systems ranges from 75-95% compared to 25-50% for surface (furrow); 70-80% solid set sprinklers and 65-75% for portable sprinkler systems (Smajstrla et al., 1988).

Important areas of concern to design a successful drip irrigation system include: 1) Is it adapted to the crop you are growing? 2) Water sources; 3) Major components of the drip system, and Installation; 4) System maintenance; and 5) How much and when to irrigate?

Is it adapted to the crops I grow?

Disposable drip systems are compatible with vegetable crops that are grown as annuals, in rows, and which do not require flooding. The main concern is the affordability of the drip system for the specific crop to be grown. Drip systems are justified for crops of high market value. Sprinkler systems are preferred for use in leafy crops, especially during Summer months, because wetting of the foliage provides for evaporative cooling during the warmers hours of the day. The release of latent heat from water under sprinkle irrigation is also used during the Winter months in the continental U.S. to protect crops from freezing injury. Crops easily adapted to drip irrigation include broccoli, cabbage, cauliflower, cucumber, eggplant, muskmelon, pepper, squash, strawberry, tomato, and watermelon.

Water Sources

Water quality tests are conducted to determine contaminant and precipitate presence in the irrigation water. Main quality factors include salinity, iron, sulfur, and calcium levels. This information may also be available from the local Municipality. Well water, with screen filters, is normally adequate for drip systems. Use sand filters for surface water sources such as streams, ponds, or rivers. Use a sand separator to separate sand particles from surface stream waters. Consider the size of the area which will be under irrigation based on the volume of irrigation water available in that location. The drip system under peak irrigation demands, should match pump and irrigation volume capacities.

Installation and Major System Components

Due to the high capital investment, and to the many technical features involved in the installation of a drip system, it is recommended that growers seek professional assistance from irrigation dealers. Locally these services are provided by such outfits as Brewer Environmental and by Wisdom Inc. The main components will include 1) Delivery system (mainline, sub-mainline, feeder tubes, and drip tube); 2) Filters; 3) Pressure regulators; and 4) Valves. Emitters normally function at a pressure of 10 psi to deliver from 0.5-2 gallons per minute. The flow rate of the drip line has to match the particular soil type. Sandy soils require drip lines with a higher flow rate to increase the lateral wetting pattern. Turbulent flow tapes are a recent development in tape types and offer several advantages over earlier types. The system should be designed to meet peak water demands of the crops to be irrigated. For example tomatoes and peppers may require peak levels of 0.4 acre inches per day. Install a water meter to record water used, and as an indicator when clogging or other irrigation problems occur.

Table 1. Approximate water requirement to grow an acre of selected vegetable crops in furrow or surface irrigation[z].

Crop	Acre inches	Gallons	Length of growth cycle (days)
Bean, snap	18	488,772	90
Broccoli	30	815,620	150
Cabbage, Chinese	24	651,696	90
Cabbage, Head	15	407,810	90
Carrots	18	488,772	120
Cauliflower	15	407,810	90-120
Celery	30	815,620	120
Cucumber	20	550,000	120
Eggplant	30	815,620	150
Ginger root	40	1,086,160	300-365
Lettuce, leafy	18	488,772	50-60
Lettuce head	18	488,772	90
Muskmelon	30	815,620	120
Onion bulb	30	815,620	120
Pepper, Bell	18	488,772	150
Potato	30	815,620	120
Squash (summer/winter)	20-30	550,000-815,620	80-180
Strawberry	48	1,303,392	365
Sweetcorn	18	488,772	90
Sweetpotato	30	815,620	150
Tomato	18	488,772	120
Watermelon	30	815,620	120

[z] Yukio Nakagawa, Univ. Hawaii Internal Manuscript. December, 1962; and Anon. 1975. Horticultural opportunities of Molokai Ranch Parcels in Hoolehua, Kaunakakai, and Kawela. Univ. Hawaii, Internal Manuscript. Thanks to Dr. Kenneth Takeda for providing this references.

System Maintenance

Factors involved in drip maintenance include: a) Daily inspection of filters; 2) Back flushing of sand filters; 3) Leaking of drip tubes; 4) Prevent mineral precipitation by dissolving with phosphoric acid; 5) Clean from bacteria, and algae with 2 ppm chlorine regular maintenance rinses or 30 ppm target treatments to clean slime clogged lines. Irrigation water acidification with phosphoric, sulfuric, hydrochloric or other acids may be necessary to reduce mineral precipitation.

How much to irrigate?

Very few studies have been conducted in Hawaii to evaluate the water use of specific vegetable crops. Water use rates have been estimated based on studies conducted in temperate areas and on the few studies conducted locally. Furthermore, reported water rates for traditionally surface irrigated crops (Table 1) should now be calibrated to allow for the different watering patterns, and for the greater water use efficiency of drip irrigation systems.

Calculation of Water Demand in Drip Systems based on known Irrigation Levels for Furrow Irrigation

Let’s use tomato as an example. Table 1 indicates that tomato requires about 18 acre inches (488,772 gallons) during a 120 day growing cycle. The number of gallons thus applied per growing cycle for tomatoes per square foot of soil=

$$\frac{488{,}772 \text{ gallons per acre}}{43560 \text{ square feet per acre}} = 11.2 \text{ gallons per square ft.}$$

If the crop is grown on 6-foot centers, it results on a total of 7260 row feet per acre. Lateral water movement from the drip line is about 15 inches on each side for heavy soils. The total wetted width in the row is then 30 inches or 2.5 feet. The total irrigated area is then (7260 ft)*(2.5 ft)= 18,150 sq ft. The number of gallons required to irrigate this area would then be: (11.2 gallons per square ft)*18,150 sq ft= 203,280 gallons/Acre. Notice that this value is less than half of the rates required to irrigate tomatoes when the entire field is wetted. When making calculations of water use based on rows feet per acre remember that values vary depending on the number of tractor rows (normally placed every 5 or 6 beds), on the particular efficiency of your drip system (normally between 80-90%) and that water may also be used at pre-planting, and for rinsing of agrichemical tanks, to flush the drip tubes, etc. Water use will also vary between locations, planting season, cultivars, incidence of pest attack, need for leaching of salts, and other management practices.

How often to irrigate?

Available water holding capacity is about 1 inch per foot for sandy soils and about 1.5-2 inches per foot of soil in heavier soils. The fraction of water taken by the plant then depends on the root volume and on the soil water holding capacity (leaching faster on sandy soils and remaining longer in heavier sandy loams or clay loams). Irrigations are usually scheduled when 50% of the available soil water has been depleted, with exact levels depending on the particular crop.

To continue with our example with tomato on 6 foot center beds, what would be the allowable water depletion from the soil between irrigations? Lets assume that these are young tomatoes with an effective root zone 10 inches deep, and that the soil water capacity is 1.5 inches per foot.

The irrigated soil volume is:
(10 inches or 0.85 ft root zone)*(2.5 ft wide wetted zone)*(7260 feet per acre) =
15,064 cubic feet per acre

The amount of water stored in this irrigate soil volume (1.5 inches per foot= ca 13%) is:
(0.13)*(15,064 cubic feet per acre)*(7.48 gallons per cubit foot of water)=
14,648 gallons per acre

Irrigations should then be conducted, at say, 50% allowable depletion, that is:
(0.50)*(14,648 gallons)= 7,324 gallons

When to Irrigate

From our example with tomatoes on 6 foot centers we now know that our total irrigation demand for the crop cycle are 203,280 gallons per Acre. We also determined that at a growth stage when root depth is 10 inches irrigations are recommended at 50% of allowable depletion (7,324 gallons). Water budgets are utilized to determine when to irrigate next. A formula is used to determine the current levels of available soil water. Current soil water content= (the previous level) + (effective rainfall) + (irrigation water) - (crop evapotranspiration (ET)). ET may be expressed as acre inches or as gallons per irrigated plot. Following with our example, if daily ET = 0.10 inches per day per acre then

Daily irrigation requirement (ET)=
(0.10 inches)*(27,152 gallons per acre-inch)=
= 2715 gallons per acre.

We determined below that 50% allowable depletion occurs at 7,324 gallons per acre. Therefore we should be able to irrigate every 2-3 days. After 2 days the water levels lost through ET would be 37% of allowable depletion and 56% after 3 days.

ET rates which range from < 0.10 during the winter to over 0.15 inches/day during the summer, can be estimated by using an open pan or may also be available from your local county extension office. Dr. I.P. Wu at UHM has developed a simple evaporation pan which would be of practical use to local producers.

Tensiometers

Neutron probes and tensiometers, available commercially, provide a simpler method to determine irrigation schedules. Typically, two tensiometers are used per irrigation block, one at 12-inch and the second at 6-inch soil depth. A tensiometer reading of 0 indicates soil water saturation. As an example, the drip system is turned on when the 12-inch tensiometer reads 20 to 30, and then turned off when the 6-inch one reads 10 or below. These values, however, have to be calibrated to match the particular crop and soil characteristics in the farm. Studies in Florida, however, indicate that irrigation scheduling based on pan evaporation data was as effective as scheduling based on tensiometers (Smajstrla and Locasio, 1990). For large planting blocks a combination of the tensiometer and pan evaporation techniques would provide the most sound irrigation management program.

Fertilizer Management Considerations

If drip irrigation is incorporated into a plastic mulch system, the fertilizer is incorporated on the beds prior to mulch placement. This approach, however, may lead to soluble salt injury, especially to the young seedlings. An alternative is to broadcast on the bed 30-40% of the total N and K, prior to planting and to place the remainder of the N and K through the drip tubes, a practice termed fertigation. For small planting blocks, of up to an acre, a "hozon" venturi injector may be used to siphon soluble fertilizer from a bucket, say, at a 1:16 ratio (gallons soluble fertilizer:gallons irrigation water). Dosatron injectors use an hydraulic device to partition fertilizer solution at several dilution rates, and are effective to

Table 2. Evapotranspiration Values Reported for Vegetable Crops from various locations

Crop	ET (inches)	Location
Bean, snap	9.69	Georgia, N. Dakota
Bean, snap	8.95	Missouri (1956)
Broccoli	19.7	Arizona (1973)
Cabbage	19.7	Arizona (1973)
Cauliflower	19.7	Arizona (1973)
Cucumber	11.3	Missouri (1956)
Carrots	16.6	Arizona (1973)
Lettuce, Head	8.5	Arizona (1973)
Muskmelon	19.1	Arizona (1973)
Muskmelon	14.67	Missouri
Onions	23.3	Arizona
Pea, green	10.98	N. Dakota (1952)
Potatoes	19.75	N. Dakota (1952)
Potatoes	24.3	Arizona (1973)
Tomatoes	19.24	Florida
Tomatoes	17.56	Georgia
Tomatoes	20.4	Missouri (1956)
Tomatoes	26.8	California
Sweetpotato	16.88	Missouri (1956)
Sweetcorn	16.00	Florida (80 days)
Sweetcorn	19.6	Arizona
Sweetcorn	19.80	Georgia
Sweetcorn	13.00	Missouri (1956)
Sweetcorn	25.20	California
Vegetables, small	10.55	N. Dakota (1952)
Vegetables, small	3.22	Florida (30 days)
Vegetables small	6.99	Florida (60 days)
Vegetables general	9.7	Florida (80 days)
Vegetables general	12.84	Florida (100 days)
Watermelons	19.24	Florida

1. Data From G. Marlow, Univ. Florida, Some ET values reported for vegetables grown at field capacity, VC499-21.

Table 3. Reported Monthly Pan Evaporation Data for Several Locations in Hawaii[1]

Location	Big Island (Pahala)	Maui ($20^{o}48'$-$156^{o}23'$)	Oahu (Waianae)	Oahu (Helemano)	Kauai (Kealia)
Elevation (ft)	860 ft.	665 ft.	10 ft.	700 ft.	15 ft.
Month	Mean pan evaporation (inches per month)				
January	4.42	4.86	4.09	3.0	5.51
February	4.3	4.85	4.37	2.94	4.79
March	4.93	6.21	6.26	4.23	5.30
April	5.36	7.37	6.81	3.74	5.13
May	5.62	8.39	7.22	4.24	6.47
June	5.7	9.74	7.94	3.98	6.71
July	6.55	10.57	8.17	5.61	7.50
Aug.	6.37	9.93	8.00	5.07	7.68
Sep.	5.56	8.83	7.27	4.74	6.50
Oct.	5.01	8.05	5.95	4.47	7.78
Nov.	4.4	5.83	4.50	3.16	8.79
Dec.	4.43	4.84	3.97	2.46	7.70

[1] Anon. 1961. Pan evaporation data, State of Hawaii. Dept. Land and Nat. Res., Honolulu. 54 pp. To calculate daily ET rates, divide the monthly ET by the number of days in the month.

cover larger irrigation blocks. Bring the drip system to full operating pressure prior to fertilizer injection. Nitrogen and K may be placed through the drip lines but P, Ca, Mg, and micronutrients are applied prior to planting. The frequency of N and K injection depends on soil type but normally once per week is sufficient (Cook and Sanders, 1991). Match the weekly fertilizer rates with the particular crop growth stage. Lower rates are applied early in the growth cycle, with rates peaking during the fruit production phase.

All fertilizer sources used through the drip lines should be highly water soluble. Common N sources include ammonium, calcium, or potassium nitrate. K sources include potassium chloride and potassium nitrate. When possible, purchase the highest analysis liquid fertilizer, which will reduce the injection cycles. Fertilizer applications should complement the nutrient levels already available in the soil, as determined by previous soil analysis determinations. The solubility of commonly used fertilizers (in pounds of product per 100 gallons of water) is: calcium nitrate, 851; potassium nitrate, 108; ammonium nitrate, 984; sodium nitrate, 608; urea, 651; diammonium phosphate, 358; and nitrate of soda potash, 980. Most of these materials dissolve best at pH of 5.8-7.8 (Sanders, 1989).

Management Considerations

Yields based on ET. In Pulehu, Maui tomato marketable yields increased linearly with evapotranspiration. Daily yields and water use efficiency peaked 20-30 days after the first harvest. This experiment used one month transplants, and first harvest was conducted 60 days after transplanting. The crop was picked every 4 days for 80 days. Yields were 99 MT/Ha with 20 inches of irrigation (Sammis and Wu, 1986).

Bed width. Preliminary research in West Florida indicates that bed with may be reduced from 30-36 inches to 24 inches in drip irrigation systems without a reduction in yields of cucumber, eggplant, muskmelon, pepper and other vegetable crops. Potential benefits of narrow beds include less polyethylene used, less energy used for bed preparation, and increased linear bed feet per acre (Maynard and Clark, 1990).

Moisture/disease interactions. A trial with drip irrigated potatoes in Guam indicated that the drip treatments improved crop growth compared to non-irrigated plots. However plots that received high irrigation levels showed reduced yields due to greater root-knot nematode and soft rot bacteria (*Erwinia*) infestations (Marutani and Cruz, 1989). Frequency of drip irrigation also had an effect on spread of crown root rot (*Phytophthora*) on bell peppers in N. Carolina (Ristaino et al., 1992).

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Table 4. Advantages and Disadvantages of Drip Irrigation and Plastic Mulch Culture[1]

Advantages
1. Reduces soil compaction in the bed.
2. Reduces soil erosion and fertilizer leaching
3. Reduces evaporation, especially when combined with plastic mulch culture
4. Cleaner produce due to less direct contact with the soil.
5. Reduces weed pressure due to protection provided by plastic mulch
6. Less water and fertilizer is used due to greater use efficiency, resulting in reduced soluble salt injury
7. Reduces diseases because foliage remains dry
8. Reduces overall labor and operating costs
9. Field operations may continue during operation.
10. Can be used on different terrain and soil conditions

Disadvantages
1. Increased cost of removal and disposal of drip tubes and plastic mulch
2. Greater initial capital investment
3. Increased management skills requred for correct operation.
4. Do not provide evaporative cooling during hot summer days.
5. Water filtration is required
6. Tube leaking may occur due to rodens, machinery, or insects.

1 From Marr et al., 1993; and Sanders, 1990.