

Microirrigation On Mulched Bed Systems: Components, System Capacities, And Management¹

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Microirrigation involves the slow application of water on, above, or below the soil surface. This encompasses trickle irrigation including drip, line source, bubbler, and micro-spray irrigation systems. Water may be applied in drops, small streams, or sprays at discrete locations or continuously along the irrigation tube lateral. Placement of the lateral and proper scheduling can allow precise application of water to the active root system of a crop. Therefore nutrient leaching and deep percolation can be minimized to increase efficiencies in applying water and chemical products through the system.

Vegetable production in southwest Florida typically utilizes plastic mulch on raised beds. The beds typically are from 6- to 10-inches in height and 24- to 36-inches in width (see Figure 1). The plastic mulch serves to retain injected fumigants and nutrients, minimize weed growth, maintain bed shape, and keeps the lower fruit away from the sandy soil. This type of bedding practice allows easy adaptation to microirrigation systems which utilize line-source or drip-type irrigation laterals. Drip irrigation laterals can be installed at the same time as the plastic mulch by modifying the mulch-laying

implement to hold a reel of tubing. Laterals are placed directly under the mulch. Some tubing manufacturers recommend burying the tube 1- to 2-inches below the soil surface. The adjustment to current cultural practices can be minimal.

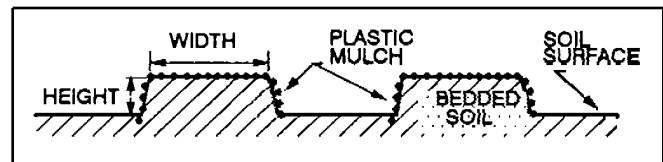


Figure 1. Cross-section of a mulched-bed.

Common irrigation practices for vegetable production in southwest Florida utilize a seepage type of subirrigation which may or may not be coupled with a microirrigation system. Most of the soils have a semi-impermeable spodic layer 18- to 36- inches below the soil surface. Water is conveyed by open ditch or pipe to lateral ditches and pumped continuously, except during rainfall, to maintain a water table 18- to 24-inches below the soil surface. Figure 2 shows some bed/ditch arrangements and typical spacings. Arrangements may range from one bed between ditches to seven beds between ditches.

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Because ditches are used for drainage in addition to irrigation, the particular bed/ditch combination required depends on the drainage characteristics of the soil as well as the infiltration characteristics. While microirrigation can eliminate the need for irrigation ditches, some provision for drainage will still be necessary and bed/ditch combinations may still be used, depending on drainage requirements. This publication will discuss the components and capacities of microirrigation systems for mulched bed systems.

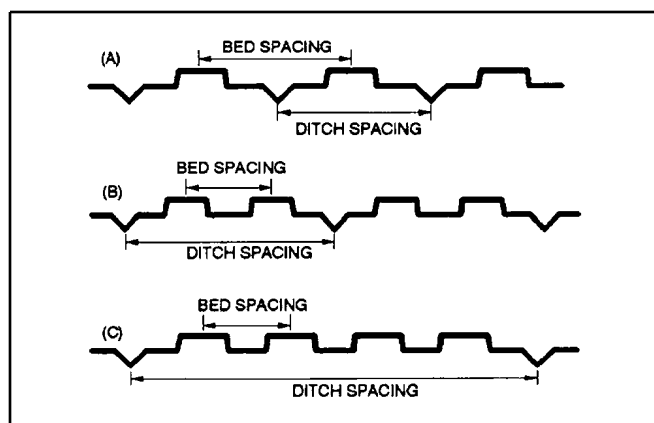


Figure 2. Bed/ditch cross-sections for (A) single-, (B) double-, and (C) four-bed arrangements.

CULTURAL CONSIDERATIONS

Because the bed/ditch arrangements can vary as shown in Figure 2, the linear bed feet of production per gross acre will vary with each bed/ditch cultural practice. Therefore it becomes necessary to discuss production and management practices in terms of bedded-feet (Bf) or bedded-feet per acre (BfAc). Table 1 can be used to determine the number of BfAc in a field based on the ditch spacing and the number of beds per ditch. The total number of Bf can be obtained by multiplying BfAc by the number of gross acres.

The BfAc index can be useful for many applications such as microirrigation tubing cost per acre, or for converting fertilizer applications from a per acre basis to per bed foot or per 100 bed feet. For example, consider a sixty-acre field farmed on 26 ft ditch centers with 3 beds per ditch. The BfAc from Table 1 is 5026 ft per acre, therefore the total Bf for 60 acres is 301,560 feet. If a drip lateral which costs 2 cents per foot is used, then the total lateral cost

would be equal to 301,560 ft * \$0.02/ft or \$6,031. This is a per acre cost of about \$100.

IRRIGATION SYSTEM COMPONENTS

The general components of a drip-type microirrigation system for mulched bed vegetable production is shown in Figure 3. The basic components include a pump and motor, a filtration system, the distribution pipe (i.e. PVC mains, submains, and manifolds), the drip- or seep-type of lateral pipelines, control valves, pressure regulators, flow meters, and pressure gauges. Flush valves at the end of each drip lateral are not necessary but are recommended to reduce the potential for clogging. If fertilizers are to be injected then, fertilizer reservoirs, injection system, and proper backflow prevention systems are required (see IFAS Extension Bulletin 217, Smajstrla et al., 1991). Automation can be achieved by adding an irrigation controller and automatic (solenoid or hydraulic) valves. This can reduce the labor requirements and possibly increase the system efficiency. Additional design information can be found in Howell et al. (1980); Nakayama and Bucks (1986); Smajstrla (1985); and Smajstrla and Zazueta (1985).

Pumps and Pumping Requirements

The type of pump required (whether centrifugal or turbine) depends upon location of the water source. Centrifugal pumps can be used with surface water supplies and shallow groundwater supplies (less than 15 to 20 feet deep). Turbine pumps are used in deeper wells. These may be submersible with an electric motor connected directly to the pump in the well or they may be shaft driven with the power unit on the ground surface.

Power units may be electrically driven or may use gasoline, diesel, or natural gas internal combustion engines. The choice of power unit will depend on several factors. Pump location will determine if electrical power is available. Submersible turbine pumps are run solely by electrical power. Electrical systems are very adaptable to automatic controllers and require less maintenance than internal combustible engines. However these systems are susceptible to power

failures which can happen when freeze protection is necessary. Therefore internal combustion engines may become necessary for these specialty purposes.

The operating pressure of the pump will depend on the design operating pressure of the drip tube laterals, the total friction losses in the system (pipe, filters, valves, meters, regulators, etc.), and the elevation of the water source with respect to the irrigation system. If the total irrigation system is to be divided and operated as several subsystems, then pressure requirements of the most critical subsystem should be used to determine the maximum system pressure. The critical subsystem is defined as the one which has the greatest flow and/or pressure requirements. This information should be determined by a qualified irrigation system designer.

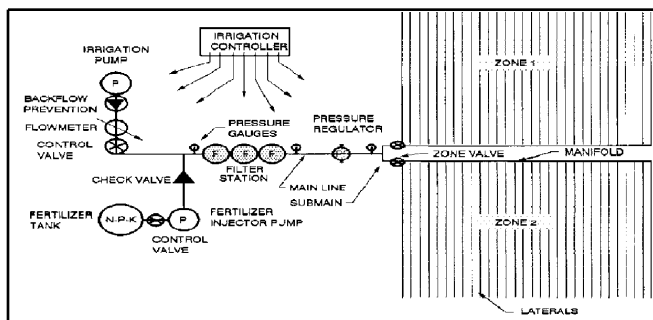


Figure 3. Layout of a basic microirrigation system.

The previously described BfAc index can be used in determining irrigation pump requirements. Microirrigation drip tubes vary in design with respect to orifice size and spacing of the orifices. Furthermore the orifice discharge rate will vary with operating pressure. Even pressure compensating emitters will have some variation. Therefore it is common to refer to drip tube discharges as flow rate per unit length such as gallons per minute (gpm) per 100 feet of pipe. If the drip tube discharge is provided in terms of gpm per emitter, the following formula can be used to obtain gpm per 100 feet.

$$Q_{pgm(100)} = \frac{(Q_{em} \times 100)}{S_e}$$

Where

$Q_{pgm(100)}$ =drip tube flow rate (gpm per 100 feet of pipe),

Q_{em} =emitter discharge (gpm), and

S_e =emitter spacing (feet).

If the emitter discharge is provided in terms of gallons per hour (GPH), then use the following formula.

$$Q_{pgm(100)} = \frac{Q_{eh}}{60} \times \frac{100}{S_e}$$

where $Q_{pgm(100)}$ and S_e are as previously defined, and Q_{eh} is the emitter discharge in gallons per hour.

Pump sizing requires a knowledge of the total flow rate (gpm) that will be pumped at any one time. Table 2 provides the flow per acre (gpm/acre) for different combinations of BfAc and drip tube discharge rate. The total flow necessary for pumping would be obtained by multiplying the gpm/acre value from Table 2 by the total number of acres irrigated at any one time. For example, if cultural practices consisted of 7000 bed feet per acre and a drip line which provided 0.50 gpm per 100 feet at the system operating pressure was used, then the system would require 35 gpm/acre. If the irrigation system was designed to irrigate in 20 acre blocks, then a pump capacity of $(20 \text{ ac} * 35 \text{ gpm/ac}) = 700 \text{ gpm}$ would be required.

Filtration

Some form of filtration is necessary with all microirrigation systems. Particulate matter suspended in the water may clog the tiny orifices of these systems. The type of filtration system will depend on the quality and type of water supply (surface or groundwater) as well as on the type of emitter system used. The size of the emitter orifice and flow path vary with respect to the manufacturer. Therefore, some emitters can pass larger particles than others. The emitter and/or drip tubing manufacturer's recommendations for filtration should be followed. This will generally be stated in terms of a mesh size such as 200 mesh.

If the water source is a surface supply then media (sand) filters should be used to remove organic matter

such as algae. Because sand and other particulates may pass through the media filter, this system should be followed with a screen or grooved disk type of filter. When groundwater (i.e. pumped from wells) is used as the water source, a screen or grooved disk filter system may be adequate. If sand is being pumped from the well, then a vortex-type sand separator may be installed in-line before the screen or disk filter. A more detailed appraisal of filtration systems is presented by Haman et al. (1987 and 1988).

Because pressure is lost across the filters, this loss needs to be included in the system design. The manufacturer of the filtration system will supply this information in their specifications. Because the filters are designed to collect particulates this loss will increase as the filter begins to clog. Pressure gauges placed on either side of the filtration system can be used to indicate when cleaning is necessary. Periodic cleaning will remove the accumulated materials and minimize the associated pressure loss. This cleaning or flushing may be done manually or automatically.

Flow Meters

All irrigation systems should be equipped with flow meters for proper management of the system. Meters may be rate or volume indicating or a combination. Rates may be obtained from a volume indicating meter by monitoring the volume of water passed in a given time period measured with a stopwatch. Flow meters may be placed at the pump, at the inlet of each subsystem, or both. Knowledge of the flow of the system will allow the irrigation manager to apply precise volumes of irrigation water and to document water use for monitoring system consistencies. Furthermore, flow meters coupled with pressure gauges can be used to monitor the pumping efficiency as well as line breaks or emitter clogging. If chemical injection is used, a knowledge of the flow is necessary for maintaining specific chemical concentration levels in the water.

Chemical Injection

Because microirrigation systems apply water within or in close proximity to the root zone of a crop, these systems are well suited for injection of fertilizers. Injection equipment is necessary to adapt

the irrigation system for fertigation and a large reservoir (500 to 1500 gal. capacity) is needed to store the liquid fertilizer. One type of system utilizes a smaller reservoir with sufficient size to hold the prescribed volume of liquid fertilizer for each irrigation cycle. In this case the larger reservoir is used only as a bulk storage facility. The chemical (fertilizer) may be added to the irrigation water by using an adjustable metering pump or some other injection device such as a venturi. The injection system may be controlled manually or automatically. Electronic monitoring of the injection rate or volume can be combined with programming of valves or injectors to be shut off after a prescribed injection volume. It is important to note that the uniformity of chemical application cannot exceed the uniformity of water application from the irrigation system. Therefore, this may be a factor in determining whether chemigation is practical for a given system. Additional information may be obtained from Smajstrla et al. (1986a and 1986b).

Florida law requires that backflow prevention systems be used on irrigation systems which have chemical injection systems installed. The level of prevention will depend on the toxicity of the chemicals involved. Backflow prevention requirements, variances, and systems are discussed in IFAS Bulletin 217 (Smajstrla, et al., 1991). In addition, county and city ordinances should be investigated. These local ordinances may be more stringent than State law requirements.

Pressure Gauges and Regulators

Pressure gauges are necessary to monitor the system operating characteristics. Decreases or increases in the system pressure can indicate broken lines or pipe blockages, respectively. As was previously discussed, pressure gauges can be used with filtration systems to indicate clogging of the filter material.

Regulators are normally required if operating conditions change from one subset to another, or if different combinations of subsets will be operated simultaneously. Under these conditions, system operating characteristics such as the pumping water level or the number of emitters per irrigation subset vary. Pressure regulators can be used to provide

constant pressures to the irrigation system, a subset, an individual lateral line, or any combination of positions. Location and the number of regulators will depend on the desired level of system control.

Pipelines

Mainline, submain pipes, and manifolds (see Figure 3) convey water from the pump to the lateral line inlets. These pipes may be aluminum, steel, PE, or PVC. Because plastic pipe is economical, relatively easy to install, and is noncorrosive to most chemicals which would be injected into the system, it is the most common pipe used in permanent systems. If PVC pipe is used it must be buried or protected from the sun.

Lateral lines may be a perforated tubing or a solid tubing with regularly spaced emitters. The spacing of perforations or emitters can vary from one or two inches to a couple of feet or more. The spacing required for a specific application depends on the ability of water to move laterally away from the emitter as well as the length of the lateral. Lateral movement in sands may be in the range of 6- to 12-inches, whereas lateral movement in heavier loamy or clayey type soils may be greater than 30-inches. Greater flow rates are associated with a greater number of emitters or perforations and will therefore require shorter lengths of run. Smaller emitter spacings make the consequence of random clogging less severe. Adjacent emitters can provide water to the area influenced by a clogged emitter if the distances are not too great. When fertilizers are injected into the system, smaller emitter spacings reduce the necessity of nutrients to move larger distances within the soil.

Flow discharges may be provided in terms of gallons per hour (gph) per emitter or as a flow per unit of pipe length, such as gpm per 100 feet or gph per 100 feet of pipe. Emitter discharge will vary with operating pressure unless the emitter has pressure compensating characteristics. Even with pressure compensation some flow variation will exist. Therefore pressure regulation and properly designed mains, submains, manifolds, and laterals are crucial to the success and uniformity of the system.

Irrigation Controllers

Irrigation systems may be operated by manual, semi-automatic, or fully automatic methods. Automation requires a controller of some type. A simple controller may be used to start and stop a pump. The level of controller sophistication can increase by adding options such as valve control (opening and closing), or chemical injection control. This may be performed with a clock-type controller or electronic-type controllers which require programming and are basically field computers. Costs can range from less than a hundred dollars to several thousand dollars. Price will depend on the desired level of sophistication as well as the number of stations that can be controlled.

SYSTEM MANAGEMENT

Irrigation Scheduling

Irrigation scheduling involves determining when to irrigate and how much water to apply. Both of these decisions will depend on the desired soil moisture management level, the crop water demand or evapotranspiration (ET) rate, the water supply in the root zone available for ET, the water holding characteristics of the soil, and the system efficiency. Atmospheric as well as soil condition vary with geographic location. Therefore variations will exist between scheduling programs.

Most of the soils in Florida are sandy and have low water holding capacities (WHC) and low cation exchange capacities (CEC, the ability of the soil to hold and exchange nutrients). Because vegetable crops have shallow root zones, frequent irrigations are necessary with these soil conditions and nutrients can easily be leached out of the root zone. Therefore proper scheduling is very important to good system management.

One of the first steps in scheduling is to determine the water storage capacity of the soil. The volume of water stored by this "reservoir" will depend on the water holding capacity of the soil, the size of effective root zone of the crop, and the lateral wetting distribution of the trickle emitter. The water holding capacity of the soil refers to the amount of water that can be held by the soil with only

negligible drainage occurring. This is analogous to the field capacity of the soil and is expressed as a percent or fraction of the soil volume. Smajstrla et al. (1985a) provide an extensive listing of textural, conductivity, and available water capacities of Florida soils.

Table 3 can be used to determine the irrigated soil volume per 100 linear bed feet of production. The wetted width represents the lateral distribution of water from the trickle tube, and the effective root zone represents the desired depth of irrigation. This latter parameter will vary with the crop and stage of production.

After determining the irrigated volume of soil, Tables 4, 5, and 6 can be used to determine the volume of water required for irrigation. All of the tables assume a 90% irrigation application efficiency. Irrigations may be scheduled after only a certain fraction of the available water in the root zone has been depleted. Irrigations must never be delayed until all available water has been depleted, because this will cause the crop to go into water stress and reduce yields. Therefore Tables 4, 5, and 6 have been compiled based on allowable depletions of 1/3, 1/2, and 2/3 of the available water for crop use. Vegetable crops are typically irrigated at 1/3 to 1/2 depletion of available water. By knowing the wetted soil volume from Table 3 and the soil water-holding capacity, the volume of water to apply per 100 linear feet of production can be determined. Most of the sandy soils of Florida have available water holding capacities of 4 to 8 percent, however, higher and lower values exist.

The length of time for the irrigation system to operate will depend on the volume of water to be applied and the rate at which it is applied. Table 7 can be used to determine the irrigation application time. This table provides application times based on the volume of water to apply (gallons per 100 feet of bed) and the emitter tubing discharge characteristics (gpm per 100 feet of tubing). If, for example, a particular irrigation requires a volume of 60 gallons per 100 linear bed feet and the microirrigation tubing discharges 0.4 gpm per 100 linear feet, then 2.5 hours is required to apply this amount of water. This irrigation cycle may be scheduled within a single 2.5

hour block or may be divided into two or more shorter duration periods which would add up to the required 2.5 hours. The latter management practice provides some time for soil water redistribution and extraction, and it will probably reduce deep percolation with higher flow emitters on very sandy soils.

Field experience, visual observations, and soil water monitoring can be used with the aforementioned procedure to provide an efficient and effective irrigation management program. A similar discussion directed toward microirrigation scheduling of orchard crops (citrus) is given by Smajstrla et al. (1985b).

Irrigation System Maintenance

All irrigation systems require routine maintenance in order to continuously provide efficient operation. A maintenance schedule should include inspection of the mechanical components as well as the irrigation lines.

The pump and power unit should be monitored to insure efficient operation. This can be done by keeping records of performance and maintenance actions. Flow rate and pressure delivered by the pump as well as the energy consumption of the power unit should be recorded frequently. Records should be maintained on at least a bi-weekly or monthly basis. Large deviations from the normal operating characteristics should be checked by a repair specialist. Routine maintenance can consist of: (a) check and lubricate all grease fittings, bearings, and oil reservoirs; (b) check for excessive noise, vibration, or leakage and make necessary adjustments; (c) inspect all electrical connections and check for frayed wires; and (d) maintain a clean facility. The above list is not complete but contains items which should be performed on a regular basis.

Filtration equipment should be continuously monitored for clogging and cleaned as necessary. Seals, gaskets, and fittings should be checked for leaks and adjusted. Control valves and pressure regulators should be checked for proper operation and flow. Lubrication may be necessary. Wires and tubes should be checked for damage and repaired as necessary.

Generally acid injection, chlorination, or use of a commercial water treatment chemical will be necessary to remove chemical precipitates or organic growths and clean the drip lines and emitters (for more information, see Ford 1979a, 1979b, 1979c, 1979d, 1979e, and 1979f). Flushing the drip lines periodically either manually or with automatic flush valves is a good management practice to remove settled debris or growths. A routine program of clogging prevention is better than attempting to clean up a clogged system.

SUMMARY

The components and operation of microirrigation systems on plastic-mulched bedded production systems were discussed. Cultural considerations such as bed size and bedded feet per acre were defined as well as system requirements and capacities. The characteristics of microirrigation systems allow precise and accurate water application to established crops. However higher levels of management and maintenance are required. Tables were presented to aid the irrigation system manager to determine the volume of water to apply and the duration of application based on soil, crop, and irrigation characteristics. Example problems demonstrating the use of these tables were discussed.

APPENDIX A

Example Problems

1. Tomatoes are grown on an Eau Gallie fine sand with an available water capacity of 0.50 inches per foot of soil. Drainage ditches are spaced on 24 foot intervals with 3 beds between ditches. The field encompasses eighteen acres and will be irrigated in three sets. What is the required pump capacity if a drip tubing which discharges 0.5 gpm per 100 feet is used?

a. From Table 1 the bed feet per acre (BfAc) is 5445 feet.

b. From Table 2, for an BfAc of 5500 ft and an emitter discharge of 0.5 gpm/100 feet, the required discharge per gross acre would be about 28 gpm. Therefore, irrigating 6

acres at a time requires a pump capacity of (6 acres * 28 gpm/acre =) 168 gpm.

2. Consider the tomato field of example problem 1. The trickle system can provide a wetted soil width of 2.0 feet. Irrigations are to be scheduled when 50% of the available water has been depleted and a 1.5 foot root zone is to be managed. What is the required time of operation for this irrigation system?

a. A wetted width of 2.0 feet and a root zone of 1.5 feet result in an irrigated soil volume of 300 cubic feet per 100 linear feet of bed (Table 3).

b. Using Table 5 for the 50% depletion level with a wetted volume of 300 cubic feet per 100 bed feet and an available water-holding capacity of 0.50 in./ft., provides that 52 gallons of water are required per 100 feet of bed per irrigation.

c. From Table 7, for a volume of 52 gallons per 100 bed feet and an emitter discharge rate of 0.5 gpm/100 feet, an application time of 1.7 to 1.8 hours is interpolated.

This irrigation period (1.7 to 1.8 hours) is required for each of the three sets. However, each set may be irrigated in two or more cycles. For example in the above situation, each of the three sets may be irrigated twice a day (morning and afternoon) for 0.9 hours each time.

APPENDIX B

Calculations

1. Calculations of bed feet per acre (BfAc); Table 1:

$$\text{Bed feet per acre} = \frac{43560 (\text{sq ft/acre}) \times \text{No. of Beds Per Ditch}}{\text{Ditch spacing (feet)}}$$

2. Calculation of discharge per gross acre; Table 2:

$$\frac{\text{Discharge Per Acre (gpm/acre)}}{\text{Discharge Per Acre (gpm/acre)}} = \frac{BfAc \times \text{Emitter Discharge (gpm/100ft)}}{100}$$

3. Calculation of soil volume; Table 3:

$$\frac{\text{Soil Volume (cu ft/100 ft)}}{\text{Soil Volume (cu ft/100 ft)}} = \frac{\text{Wetted Width (ft)} \times \text{Root Zone (ft)} \times 100 \text{ ft}}{\text{Soil Volume (cu ft/100 ft)}}$$

4. Calculation of the volume of water to be applied per 100 linear feet; Tables 4, 5, and 6:

$$\frac{\text{Volume of Water to Apply Per 100 Feet of Bed}}{\text{Volume of Water to Apply Per 100 Feet of Bed}} = 7.48 \times \frac{\text{Soil Volume (cu ft/100ft)} \times \frac{\text{Water Holding Capacity (fraction)}}{\text{Irrigation Efficiency}} \times \frac{\text{Allowable Depletion (fraction)}}{\text{Irrigation Efficiency}}}{\text{Irrigation Efficiency}}$$

5. Calculation of Irrigation time; Table 7:

$$\frac{\text{Irrigation Application Time, hours}}{\text{Irrigation Application Time, hours}} = 60 \times \frac{\text{Volume of Water to Apply (gal/100ft)}}{\text{Emitter Discharge Rate (gpm/100ft)}}$$

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Table 1. Bed-feet per acre (BfAc) based on ditch spacing and the number of beds per ditch.

| Ditch Spacing (feet) | Number of beds per ditch | | | | | | |
|----------------------|--------------------------|------|------|------|------|-------|-------|
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 3 | 14520 | ---- | ---- | ---- | ---- | ---- | ---- |
| 4 | 10890 | ---- | ---- | ---- | ---- | ---- | ---- |
| 5 | 8712 | ---- | ---- | ---- | ---- | ---- | ---- |
| 6 | 7260 | ---- | ---- | ---- | ---- | ---- | ---- |
| 8 | 5445 | ---- | ---- | ---- | ---- | ---- | ---- |
| 10 | 4356 | 8712 | ---- | ---- | ---- | ---- | ---- |
| 12 | 3630 | 7260 | ---- | ---- | ---- | ---- | ---- |
| 14 | 3111 | 6223 | 9334 | ---- | ---- | ---- | ---- |
| 16 | ---- | 5445 | 8168 | ---- | ---- | ---- | ---- |
| 18 | 4840 | 7260 | 9680 | ---- | ---- | ---- | ---- |
| 20 | ---- | 4356 | 6534 | 8712 | ---- | ---- | ---- |
| 22 | ---- | ---- | 5940 | 7920 | 9900 | ---- | ---- |
| 24 | ---- | ---- | 5445 | 7260 | 9075 | ---- | ---- |
| 26 | ---- | ---- | 5026 | 6702 | 8377 | 10052 | ---- |
| 28 | ---- | ---- | ---- | 6223 | 7779 | 9334 | ---- |
| 30 | ---- | ---- | ---- | 5808 | 7260 | 8712 | 10164 |
| 32 | ---- | ---- | ---- | 5445 | 6806 | 8168 | 9529 |
| 34 | ---- | ---- | ---- | ---- | 6406 | 7687 | 8968 |
| 36 | ---- | ---- | ---- | ---- | 6050 | 7260 | 8470 |
| 38 | ---- | ---- | ---- | ---- | 5732 | 6879 | 8024 |
| 40 | ---- | ---- | ---- | ---- | ---- | 6534 | 7623 |

If the field does not contain ditches then substitute the bed spacing for ditch spacing and use the 1 bed per ditch column to determine the bed-feet per acre.

Table 2. Discharge per gross acre (gpm/acre) based on irrigated bed feet and emitter discharge.

| Bed Feet Per Acre (BfAc) | Emitter Discharge (gpm/100 feet) | | | | | | |
|--------------------------|----------------------------------|------|------|------|------|------|------|
| | 0.25 | 0.30 | 0.40 | 0.50 | 0.75 | 1.00 | 1.50 |
| 3000 | 8 | 9 | 12 | 15 | 23 | 30 | 45 |
| 3500 | 9 | 11 | 14 | 18 | 26 | 35 | 53 |
| 4000 | 10 | 12 | 16 | 20 | 30 | 40 | 60 |
| 4500 | 11 | 14 | 18 | 23 | 34 | 45 | 68 |
| 5000 | 13 | 15 | 20 | 25 | 38 | 50 | 75 |
| 5500 | 14 | 17 | 22 | 28 | 41 | 55 | 83 |
| 6000 | 15 | 18 | 24 | 30 | 45 | 60 | 90 |
| 6500 | 16 | 20 | 26 | 33 | 49 | 65 | 98 |
| 7000 | 18 | 21 | 28 | 35 | 53 | 70 | 105 |
| 7500 | 19 | 23 | 30 | 38 | 56 | 75 | 113 |
| 8000 | 20 | 24 | 32 | 40 | 60 | 80 | 120 |
| 8500 | 21 | 26 | 34 | 43 | 64 | 85 | 128 |

Table 2. Discharge per gross acre (gpm/acre) based on irrigated bed feet and emitter discharge.

| Bed Feet Per Acre (BfAc) | Emitter Discharge (gpm/100 feet) | | | | | | |
|--------------------------------|----------------------------------|------|------|------|------|------|------|
| | 0.25 | 0.30 | 0.40 | 0.50 | 0.75 | 1.00 | 1.50 |
| 9000 | 23 | 27 | 36 | 45 | 68 | 90 | 135 |
| 9500 | 24 | 28 | 38 | 48 | 71 | 95 | 143 |
| 10000 | 25 | 30 | 40 | 50 | 75 | 100 | 150 |
| 10500 | 26 | 31 | 42 | 53 | 79 | 105 | 158 |
| 11000 | 28 | 33 | 44 | 55 | 83 | 110 | 165 |

Table 3. Soil volume (cubic feet) irrigated per 100 linear bed feet.

| Wetted Width (feet) | Effective Root Zone (depth to be irrigated, feet) | | | | | |
|---------------------------|--|-----|-----|-----|-----|-----|
| | 0.5 | 1.0 | 1.5 | 2.0 | 2.5 | 3.0 |
| .5 | 25 | 50 | 75 | 100 | 125 | 150 |
| 1.0 | 50 | 100 | 150 | 200 | 250 | 300 |
| 1.5 | 75 | 150 | 225 | 300 | 375 | 450 |
| 2.0 | 100 | 200 | 300 | 400 | 500 | 600 |
| 2.5 | 125 | 250 | 375 | 500 | 625 | 750 |
| 3.0 | 150 | 300 | 450 | 600 | 750 | 900 |

Table 4. Approximate volume of water to apply (gallons) per 100 linear feet of bed for a given wetted soil volume available water-holding capacity and an allowable depletion of 1/3.

| Wetted Soil Vol. Per 100 ft. (cu. ft.) | Available Water-Holding Capacity (Fraction by Volume) | | | | | | | |
|---|--|------|------|------|------|------|------|------|
| | 0.02 | 0.04 | 0.06 | 0.08 | 0.10 | 0.12 | 0.14 | 0.16 |
| 25 | 2 | 3 | 4 | 6 | 7 | 9 | 10 | 11 |
| 50 | 3 | 6 | 9 | 11 | 14 | 17 | 20 | 23 |
| 75 | 4 | 9 | 13 | 17 | 21 | 26 | 30 | 34 |
| 100 | 6 | 11 | 17 | 23 | 29 | 34 | 40 | 46 |
| 125 | 7 | 14 | 21 | 29 | 36 | 43 | 50 | 57 |
| 150 | 9 | 17 | 26 | 34 | 43 | 51 | 60 | 69 |
| 175 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 |
| 200 | 11 | 23 | 34 | 46 | 57 | 69 | 80 | 91 |
| 225 | 13 | 26 | 39 | 51 | 64 | 77 | 90 | 103 |
| 250 | 14 | 29 | 43 | 57 | 71 | 86 | 100 | 114 |
| 275 | 16 | 31 | 47 | 63 | 79 | 94 | 110 | 126 |
| 300 | 17 | 34 | 51 | 69 | 86 | 103 | 120 | 137 |
| 350 | 20 | 40 | 60 | 80 | 100 | 120 | 140 | 160 |
| 400 | 23 | 46 | 69 | 91 | 114 | 137 | 160 | 183 |
| 450 | 26 | 51 | 77 | 103 | 129 | 154 | 180 | 206 |
| 500 | 29 | 57 | 86 | 114 | 143 | 171 | 200 | 229 |

Table 4. Approximate volume of water to apply (gallons) per 100 linear feet of bed for a given wetted soil volume available water-holding capacity and an allowable depletion of 1/3.

| Wetted Soil Vol. Per 100 ft. (cu. ft.) | Available Water-Holding Capacity (Fraction by Volume) | | | | | | | |
|---|--|------|------|------|------|------|------|------|
| | 0.02 | 0.04 | 0.06 | 0.08 | 0.10 | 0.12 | 0.14 | 0.16 |
| 550 | 31 | 63 | 94 | 126 | 157 | 189 | 220 | 251 |
| 600 | 34 | 69 | 103 | 137 | 171 | 206 | 240 | 274 |
| 700 | 40 | 80 | 120 | 160 | 200 | 240 | 280 | 320 |
| 800 | 46 | 91 | 137 | 183 | 229 | 274 | 320 | 366 |
| 900 | 51 | 103 | 154 | 206 | 257 | 309 | 360 | 411 |
| An irrigation application efficiency of 90% was assumed | | | | | | | | |

Table 5. Approximate volume of water to apply (gallons) per 100 linear feet of bed for a given wetted soil volume available water-holding capacity and an allowable depletion of 1/2.

| Wetted Soil Vol. Per 100 ft. (cu. ft.) | Available Water-Holding Capacity (Fraction by Volume) | | | | | | | |
|---|--|------|------|------|------|------|------|------|
| | 0.02 | 0.04 | 0.06 | 0.08 | 0.10 | 0.12 | 0.14 | 0.16 |
| 25 | 2 | 4 | 7 | 8 | 11 | 13 | 15 | 17 |
| 50 | 4 | 9 | 13 | 17 | 21 | 26 | 30 | 34 |
| 75 | 6 | 13 | 20 | 26 | 33 | 39 | 45 | 52 |
| 100 | 8 | 17 | 26 | 35 | 43 | 52 | 60 | 69 |
| 125 | 10 | 22 | 33 | 43 | 54 | 65 | 76 | 86 |
| 150 | 13 | 26 | 39 | 52 | 65 | 78 | 91 | 104 |
| 175 | 15 | 30 | 46 | 61 | 76 | 91 | 106 | 121 |
| 200 | 17 | 35 | 52 | 69 | 89 | 104 | 121 | 138 |
| 225 | 20 | 39 | 58 | 78 | 97 | 117 | 136 | 156 |
| 250 | 22 | 43 | 65 | 87 | 108 | 130 | 151 | 173 |
| 275 | 24 | 48 | 71 | 95 | 119 | 143 | 167 | 190 |
| 300 | 26 | 52 | 78 | 104 | 130 | 156 | 182 | 208 |
| 350 | 30 | 61 | 91 | 121 | 152 | 182 | 212 | 242 |
| 400 | 35 | 69 | 104 | 139 | 173 | 208 | 242 | 277 |
| 450 | 39 | 78 | 117 | 156 | 195 | 234 | 273 | 312 |
| 500 | 43 | 87 | 130 | 173 | 216 | 260 | 303 | 346 |
| 550 | 48 | 95 | 143 | 191 | 238 | 286 | 333 | 381 |
| 600 | 52 | 104 | 156 | 208 | 260 | 312 | 364 | 416 |
| 700 | 61 | 121 | 182 | 242 | 303 | 364 | 424 | 485 |
| 800 | 69 | 139 | 208 | 277 | 346 | 416 | 485 | 554 |
| 900 | 78 | 156 | 234 | 312 | 390 | 468 | 545 | 623 |
| An irrigation application efficiency of 90% was assumed | | | | | | | | |

Table 6. Approximate volume of water to apply (gallons) per 100 linear feet of bed for a given wetted soil volume available water-holding capacity and an allowable depletion of 2/3.

| Wetted Soil Vol. per 100 ft. (cu. ft.) | Available Water-Holding Capacity (Fraction by Volume) | | | | | | | |
|---|--|------|------|------|------|------|------|------|
| | 0.02 | 0.04 | 0.06 | 0.08 | 0.10 | 0.12 | 0.14 | 0.16 |
| 25 | 3 | 6 | 9 | 11 | 14 | 17 | 20 | 23 |
| 50 | 6 | 11 | 17 | 23 | 29 | 34 | 40 | 46 |
| 75 | 9 | 17 | 26 | 34 | 43 | 51 | 60 | 69 |
| 100 | 11 | 23 | 34 | 46 | 57 | 69 | 80 | 91 |
| 125 | 14 | 29 | 43 | 57 | 71 | 86 | 100 | 114 |
| 150 | 17 | 34 | 51 | 69 | 86 | 103 | 120 | 137 |
| 175 | 20 | 40 | 60 | 80 | 100 | 120 | 140 | 160 |
| 200 | 23 | 46 | 69 | 91 | 114 | 137 | 160 | 183 |
| 225 | 26 | 51 | 77 | 103 | 129 | 154 | 180 | 206 |
| 250 | 29 | 57 | 86 | 114 | 143 | 171 | 200 | 229 |
| 275 | 31 | 63 | 94 | 126 | 157 | 189 | 220 | 251 |
| 300 | 34 | 69 | 103 | 137 | 171 | 206 | 240 | 274 |
| 350 | 40 | 80 | 120 | 160 | 200 | 240 | 280 | 320 |
| 400 | 46 | 91 | 137 | 183 | 229 | 274 | 320 | 366 |
| 450 | 51 | 103 | 154 | 206 | 257 | 309 | 360 | 411 |
| 500 | 57 | 114 | 171 | 229 | 286 | 343 | 400 | 457 |
| 550 | 63 | 126 | 189 | 251 | 314 | 377 | 440 | 503 |
| 600 | 69 | 137 | 206 | 274 | 343 | 411 | 480 | 549 |
| 700 | 80 | 160 | 240 | 320 | 400 | 480 | 560 | 640 |
| 800 | 91 | 183 | 274 | 366 | 457 | 549 | 640 | 731 |
| 900 | 103 | 206 | 309 | 411 | 514 | 617 | 720 | 823 |

An irrigation application efficiency of 90% was assumed

Table 7. Irrigation time per application (hours).

| Volume of Water To Apply (gallons per 100 bed ft.) | Emitter Flow Rate (gpm per 100 feet) | | | | | | |
|---|--------------------------------------|------|------|------|------|------|------|
| | 0.25 | 0.30 | 0.40 | 0.50 | 0.75 | 1.00 | 1.50 |
| 2.0 | .1 | .1 | **** | **** | **** | **** | **** |
| 4.0 | .3 | .2 | .2 | .1 | **** | **** | **** |
| 6.0 | .4 | .3 | .3 | .2 | .1 | .1 | **** |
| 8.0 | .5 | .4 | .3 | .3 | .2 | .1 | **** |
| 10.0 | .7 | .6 | .4 | .3 | .2 | .2 | .1 |
| 15.0 | 1.0 | .8 | .6 | .5 | .3 | .3 | .2 |
| 20.0 | 1.3 | 1.1 | .8 | .7 | .4 | .3 | .2 |
| 30.0 | 2.0 | 1.7 | 1.3 | 1.0 | .7 | .5 | .3 |
| 40.0 | 2.7 | 2.2 | 1.7 | 1.3 | .9 | .7 | .4 |
| 50.0 | 3.3 | 2.8 | 2.1 | 1.7 | 1.1 | .8 | .6 |
| 60.0 | 4.0 | 3.3 | 2.5 | 2.0 | 1.3 | 1.0 | .7 |

Table 7. Irrigation time per application (hours).

| Volume of Water To Apply (gallons per 100 bed ft.) | Emitter Flow Rate (gpm per 100 feet) | | | | | | |
|---|--------------------------------------|------|------|------|------|------|------|
| | 0.25 | 0.30 | 0.40 | 0.50 | 0.75 | 1.00 | 1.50 |
| 70.0 | 4.7 | 3.9 | 2.9 | 2.3 | 1.6 | 1.2 | .8 |
| 80.0 | 5.3 | 4.4 | 3.3 | 2.7 | 1.8 | 1.3 | .9 |
| 90.0 | 6.0 | 5.0 | 3.8 | 3.0 | 2.0 | 1.5 | 1.0 |
| 100.0 | 6.7 | 5.6 | 4.2 | 3.3 | 2.2 | 1.7 | 1.1 |
| 150.0 | 10.0 | 8.3 | 6.3 | 5.0 | 3.3 | 2.5 | 1.7 |
| 200.0 | 13.3 | 11.1 | 8.3 | 6.7 | 4.4 | 3.3 | 2.2 |
| 300.0 | 20.0 | 16.7 | 12.5 | 10.0 | 6.7 | 5.0 | 3.3 |
| 400.0 | **** | 22.2 | 16.7 | 13.3 | 8.9 | 6.7 | 4.4 |
| 600.0 | **** | **** | **** | 20.0 | 13.3 | 10.0 | 6.7 |
| 800.0 | **** | **** | **** | **** | 17.8 | 13.3 | 8.9 |

****Irrigation times less than 0.1 hours or greater than 24 hours are not presented.