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TIPS ON IRRIGATING VEGETABLES

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CONTENTS

page
Pre-irrigation 2
When to irrigate 4
Your soil as an irrigation guide 4
Which irrigation system is best? 4
Sprinklers
  Sprinklers for starting vegetables 5
  How often to sprinkle vegetables 5
  How fast should sprinklers apply water? 5
  Weed control 5
  Choosing your sprinkler system 5
  Can you irrigate the whole field at one time?. 7
  Pick the right pump. 7
  Nozzle wear: How far gone are your sprinkler nozzles? 8
  Screen out debris. 8
  Preparing the seedbed for sprinkler irrigation 8
  Placement of sprinkler pipe. 9
  Laying down the irrigation pipes 9
Furrow irrigation
  Wide furrows vs. narrow furrows. 9
  How much should furrows slope? 10
  Furrow stream size 10
  How long to irrigate 10
  After irrigating: did the water go where you wanted it to? 11
  How water soaks into most kinds of soils 11
Drip irrigation. 13
Irrigating hardpans, claypans, and compacted soils 13
Saving on the water bill 14
Appendix (List of equivalents) 15

TABLES

Table 1. Approximate rooting depth of vegetables. 2
Table 2. Inches water to pre-irrigate a dry soil to different depths. 2
Table 3. Estimating soil moisture by feel 3
Table 4. Which irrigation system is best? 4
Table 5. Application rates for various nozzle sizes, pressures, and spacings. . 6
Table 6. Guide for selecting size of aluminum pipe for sprinkler lateral line . 7
Table 7. Guide to main line pipe sizes. 7
Table 8. Flow of water required to operate solid set sprinkler systems. 8
Table 9. Continuous power output required at tractor P.T.O. to pump water . . . 8
Table 10. Maximum furrow stream size 10
Table 11. Maximum allowable time for water to go from one end of field to other.10
Table 12. Maximum recommended furrow lengths 10

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Irrigation costs are going up. With irrigation taking a larger share of growing costs, you'll want to find better ways to irrigate. This publication contains pointers that will help you irrigate more efficiently.

PRE-IRRIGATION

The first irrigation for most vegetables is a deep pre-irrigation--except where rains have already wet the soil as deep as most roots will go. Pre-irrigation leaches salts and can save water by trimming the number of irrigations needed later.

How deep should you pre-irrigate? Wet the soil a little deeper than your crop's rooting depth. Approximate rooting depth for vegetables is shown in Table 1.

Knowing your crop's rooting depth can also help you decide how long to run the water in later irrigations. Using Table 2, you can tell roughly how much water you'll need to pre-irrigate a dry soil to a desired depth.

Table 1. Approximate rooting depth of vegetables(1)

Crop	Depth
Asparagus, pumpkin, winter squash, seeded tomato, seeded watermelon, lima beans, sweet potato	over 4 feet
Bush and pole beans, cantaloupe, carrot, cucumber, eggplant beets, peas, pepper, summer squash	3 to 4 feet
Broccoli, cabbage, cauliflower, corn, lettuce, radish, garlic, onion, celery, potato	1-1/2 to 2 feet

Table 2. Inches water to pre-irrigate a dry soil to different depths (approx.) (2)

Soil Type(3)	Inches water per foot soil depth	Inches water to reach 6' deep
Clay	1.4 - 1.8	8.6 - 10.8
Silty clay	1.6 - 1.9	9.6 - 11.4
Sandy clay	1.6 - 1.9	9.6 - 11.4
Silty clay loam	2.2 - 2.3	13.0 - 13.7
Clay loam	2.0 - 2.2	12.2 - 13.0
Sandy clay loam	2.0 - 2.2	12.2 - 13.0
Silt loam	1.8 - 2.0	10.8 - 12.2
Loam	1.7 - 1.9	10.1 - 11.4
Very fine sandy loam	1.7 - 1.9	10.1 - 11.4
Fine sandy loam	1.2 - 1.4	7.2 - 8.6
Sandy loam	1.1 - 1.3	6.5 - 7.9
Loamy very fine sand	1.1 - 1.3	6.5 - 7.9
Loamy fine sand	1.0 - 1.2	5.8 - 7.2
Loamy sand	0.7 - 1.0	4.3 - 5.8
Very fine sand	0.7 - 1.0	4.3 - 5.8
Fine sand	0.7 - 1.0	4.3 - 5.8
Sand	0.7 - 1.0	4.3 - 5.8
Coarse sand and gravel	0.4 - 0.7	2.2 - 4.3

(1) The figures are averages for mature plants. Root depth varies, depending on soil profile, crop variety, whether you direct seeded or transplanted, etc.
(2) Based on available water holding capacity; plants have dried soil to permanent wilting point, 15 ATM.
(3) Assumes the soil is uniform throughout irrigation depth.

Table 3. Estimating soil moisture by feel.

SOIL MOISTURE LEVEL	How Soil Feels or Looks			
	COARSE (sand)	LIGHT (Loamy sand, sandy loam)	MEDIUM (fine sandy loam, silt loam)	HEAVY (clay loam, clay)
No available soil moisture. Plants wilt. Irrigation required. (1st Range)	Dry, loose, single grained, flows through fingers. No stain or smear on fingers.	Dry, loose, clods easily crushed and will flow through fingers. No stain or smear on fingers.	Crumbly, dry, powdery, will barely maintain shape. Clods, breaks down easily. May leave slight smear or stain when worked with hands or fingers.	Hard, firm baked, cracked. Usually too stiff or tough to work or ribbon(1) by squeezing between thumb or forefinger. May leave slight smear or stain.
Moisture is available, but level is low. Irrigation needed. (2nd Range)	Appears dry; will not retain shape when squeezed in hand.	Appears dry; may tend to make a cast when squeezed in hand, but seldom will hold together.	May form a weak ball(2) under pressure but will still be crumbly. Color is pale with no obvious moisture.	Pliable, forms a ball; will ribbon but usually breaks or is crumbly. May leave slight stain or smear.
Moisture is available. Level is high. Irrigation not yet needed. (3rd Range)	Color is darkened with obvious moisture. Soil may stick together in very weak cast or ball.	Color is darkened with obvious moisture. Soil forms weak ball or cast under pressure. Slight finger stain, but no ribbon when squeezed between thumb and forefinger.	Color is darkened from obvious moisture. Forms a ball. Works easily, clods are soft with mellow feel. Will stain finger and have slick feel when squeezed.	Color is darkened with obvious moisture. Forms good ball. Ribbons easily, has slick feel. Leaves stain on fingers.
Soil moisture level following an irrigation. (4th Range)	Appears and feels moist. Color is darkened. May form weak cast or ball. Will leave wet outline or slight smear on hand.	Appears and feels moist. Color is darkened. Forms cast or ball. Will not ribbon, but will show smear or stain and leave wet outline on hand.	Appears and feels moist. Color is darkened. Has a smooth, mellow feel. Forms ball and will ribbon when squeezed. Stains and smears. Leaves wet outline on hand.	Color is darkened. Appears moist; may feel sticky. Ribbons out easily, smears and stains hand, leaves wet outline. Forms good ball.

(1) Ribbon is formed by squeezing and working soil between thumb and forefinger.
(2) Cast or ball is formed by squeezing soil in hand.

WHEN TO IRRIGATE

After pre-irrigation, later irrigations depend on soil, weather, and the crop.

1. Coarse or sandy soil needs water more often than loam, silt, and most clay.
2. Soil dries out faster when the weather warms up.
3. Wind speeds up soil drying.
4. Sunny weather dries soil faster than cloudy weather.
5. When plants are large, they use more water.

Since water needs change through the seasons, irrigating by calendar is not recommended.

YOUR SOIL AS AN IRRIGATION GUIDE

One way to decide whether to irrigate is to use a shovel or auger and feel the soil where most of your crop's roots are. Table 3 shows you how to tell the soil's moisture by feel. This is a general guide only, but the method has been used for years by many farmers. Of course, you must also consider root depth, recent weather, and when the field was last irrigated.

WHICH IRRIGATION SYSTEM IS BEST?

Sprinkler, furrow, and drip irrigation systems each have advantages and disadvantages as shown in Table 4 below:

Table 4. Which irrigation system is best?

System	Advantages	Disadvantages
Sprinkler	. Provides good soil moisture and aeration . Leaches excess salts . Reduces crusting, making seedling emergence easier . Relatively uniform water application . Can be used on unleveled land	. High initial cost . Encourages weed growth between rows . High energy requirement . May encourage some diseases . Wet soil may interfere with timing of pesticide sprays
Furrow	. Most commonly used . Lowest initial cost	. Less even water distribution . Crusting problems . Can concentrate salts near plants . Requires land leveling
Drip	. Usually requires less water . Can cut irrigation labor cost . Allows picking and spraying while irrigating . May stretch limited water supply . Can be used on sloped land	. Less commonly used on vegetables (except strawberries, pole tomatoes) . High capital cost . Resetting system each year costly . Requires some technical expertise

SPRINKLERS

Sprinklers for starting vegetables

The investment for sprinklers is high, yet a growing number of farmers use them to bring up a stand of vegetables because of the advantages listed in Table 4. They are not used for beans or corn unless they are planted shallow--about one inch deep.

How often to sprinkle vegetables

Growers usually get best results by sprinkling daily until the crop comes up. Brief (one hour) daily irrigations help soften the crust and keep salts moving downward. Of course, seedlings must not be kept waterlogged or they will die from damping off. Once the stand is established, you can move sprinklers to the next field.

How fast should sprinklers apply water?

Your sprinkler system should not apply water faster than it soaks into the soil. Putting water on faster than the soil's intake rate results in puddling, the main cause of soil crusting. Sprinkler systems that apply 0.1 to 0.15 inches per hour have proven successful on a wide range of California soils.

But on some soils--those with strong clay or silt characteristics--even that much water is too much. To prevent crusting on such soils, only about 0.06 inches per hour is applied. These low sprinkling rates don't mean you'll spend too much time sprinkling a field. That's because a system can irrigate a field in the same time at low application rates as high application rates, but you'll have to buy more lateral lines.

Weed control

It is especially important to have good weed control when using sprinklers since sprinkling also germinates a high percentage of weed seeds.

Choosing your sprinkler system

1. Select sprinklers that wet a circle at least 60 to 65 feet in diameter (conventional pressure systems, 50 to 65 pounds per square inch--psi).

2. Have a nozzle size that won't put water on faster than your soils can take it. The 5/64 to 3/32 inch size works well for most soils. On heaviest (fine textured) soils, the 5/64 inch size can prevent crusting better than the 3/32 inch size, though the smaller nozzle's pattern is affected more by wind.

3. Use 50 to 65 psi at the nozzles for uniform sprinkling and to prevent crusts. New low pressure systems at about 30 to 40 psi may have smaller droplets and cause less crusting.

4. Spacing between sprinklers along the pipe depends on wind. Sprinkler spacing should not be over 65 percent of rated diameter of spray with no wind, 60 percent of the diameter for winds up to five miles per hour, and 50 percent for winds up to 10 miles per hour. Between laterals, a spacing of 40 to 45 feet is often suggested for conventional, high pressure systems. New low pressure systems need closer spacings, usually 40' x 40'.

Choosing a sprinkler system will be easier if you use Tables 5-9. For example, if you want to avoid crusting by applying water at 0.1 inch per hour on quarter-mile long fields (1,320 feet), Table 3 shows that 5/64 inch nozzles at 50 psi on 30x40 foot spacings will give you 0.1 inch per hour.

This setup puts on 1.25 gpm (gallons per minute). See Table 5. With 1,320 foot rows and 30 foot long pipe, you'll need 44 sprinklers/row. $\frac{1320}{30} = 44$

Table 6 shows that three-inch pipe is more than large enough to put on the 1.25 gpm, but a two-inch line isn't big enough (maximum is 34 sprinklers at 1.25 gpm).

If you put the main line through the center of the field, a two-inch line would handle up to 34 sprinklers running each way (68 total) and that's more than enough for the 44 sprinklers needed in this example. (See Table 7.)

Table 5. Application rates for various nozzle sizes, pressures, and spacings.

Nozzle Size	Pressure (psi)(1)	Discharge(2) (gpm)(3)	Diameter(4) of spray (feet)	Application rate at spacings (inch/hour) 20'x40	30'x40'	30'x45'	40'x40'
1/16	35	0.69	59-61	.080	.055		
1/16	40	0.74	60-62	.086	.059		
1/16	45	0.76	60-72	.091	.061		
1/16	50	0.80	61-73	.093	.064		
1/16	55	0.85	62-74	.102	.068		
1/16	60	0.88	63-75	.106	.071		
5/64	35	1.08	63-65	.126	.086	.077	.066
5/64	40	1.15	64-66	.134	.092	.082	.069
5/64	45	1.19	59-73	.143	.095	.085	.072
5/64	50	1.25	62-72	.150	.100	.089	.075
5/64	55	1.30	64-74	.156	.104	.094	.079
5/64	60	1.36	67-76	.164	.110	.097	.082
3/32	35	1.55	68-70		.124	.110	.093
3/32	40	1.66	69-71		.132	.118	.099
3/32	45	1.72	68-76		.137	.123	.103
3/32	50	1.80	69-77		.145	.128	.108
3/32	55	1.88	70-78		.151	.134	.113
3/32	60	1.98	71-79		.159	.141	.119
7/64	35	2.11	71-73		.169	.150	.127
7/64	40	2.25	73-75		.180	.160	.135
7/64	45	2.32	71-78		.185	.165	.139
7/64	50	2.44	72-80		.196	.174	.141
7/64	55	2.56	74-81		.205	.182	.154
7/64	60	2.69	76-82		.216	.192	.161
1/8	35	2.77	76-78		.221	.197	.167
1/8	40	2.96	77-79		.236	.211	.178
1/8	45	3.04	76-82		.243	.217	.182
1/8	50	3.22	78-82		.257	.230	.193
1/8	55	3.39	79-83		.271	.242	.204
1/8	60	3.55	80-84		.284	.253	.213

(1) PSI--pounds per inch.
(2) Showing a three-digit number here is only to indicate the progression as nozzle size and pressure increase. Sprinkler equipment seldom performs so precisely.
(3) GPM--gallons per minute.
(4) Shows range of diameters of spray for different makes and models of sprinklers.

Table 6. Guide for selecting size of aluminum pipe for sprinkler lateral line.

Sprinkler Discharge (gpm)	Maximum number of sprinklers to use on single lateral line: 30-foot sprinkler spacing, Pipe size: 2 inch	3 inch	4 inch	40-foot sprinkler spacing, Pipe size: 2 inch	3 inch	4 inch
.75	47	95	200	43	85	180
1.00	40	80	150	36	72	125
1.25	34	69	118	31	62	104
1.50	30	62	100	28	56	94
1.75	27	56	92	25	50	83
2.00	25	51	84	23	46	76
2.25	23	47	78	21	43	71
2.50	21	44	73	19	40	66
2.75	20	42	68	18	38	62
3.00	19	40	65	17	36	58
3.25	18	38	62	16	34	56
3.50	17	36	59	15	32	53
3.75	16	34	56	14	31	51
4.00	16	33	54	14	30	48

Can you irrigate the whole field at one time?

Table 8 tells you how many acres you can irrigate at one time using the precipitation rate you're aiming for. This table also shows how much water you'll need to order from the district if you're not pumping from a well. Be sure to order enough water so the pump doesn't run dry.

Pick the right pump

Tables 5 and 8 can help you figure the size of pump you'll need if you are designing a system. Power sources for pumps have a horsepower--hp--rating to match the pump. But many sprinkler systems used for seed germination have separate pumps designed to be driven from the power-take-off--p.t.o.--of a farm tractor. The tractor used to drive the pump must be able to provide the needed hp at the p.t.o. Table 9 shows the hp needed to drive a pump operating at 75 percent efficiency for different waterflow and pressure requirements.

Table 7. Guide to main line pipe sizes(1)

Distance (feet)	Waterflow (gpm): 200	400	600	800	1000	1200	1400	1600	1800
	Pipe diameter (inches)								
200	3	4	5	5	6	6	6	7	7
400	4	5	5	6	6	7	7	8	8
600	4	5	6	7	7	7	8	8	8
800	4	5	6	7	7	8	8	8	10
1000	5	6	6	7	8	8	8	10	10
1200	5	6	7	7	8	8	10	10	10

(1) Using aluminum pipe (C=120) with pressure losses ranging from 5 to 15 psi, average about 10.

Table 8. Flow of water required to operate solid set sprinkler systems.

Precipitation Rate (inch/hour)	Acres irrigated per set									
	4		8		12		16		20	
	gpm	cfs(1)	gpm	cfs	gpm	cfs	gpm	cfs	gpm	cfs
.06	108	.5	217	.5	326	1.0	435	1.0	543	1.5
.08	145	.5	290	1.0	435	1.0	580	1.5	725	2.0
.10	181	.5	362	1.0	543	1.5	724	2.0	905	2.5
.12	217	.5	435	1.0	652	1.5	870	2.0	1086	2.5
.15	271	1.0	543	1.5	815	2.0	1086	2.5	1360	3.5
.20	362	1.0	724	2.0	1086	2.5	1448	2.5	1810	4.5

Table 9. Continuous power output required at tractor P.T.O. to pump water.

Pressure(2) (psi)	Head(2) (feet)	Flow (gpm)								
		100	200	300	400	500	600	700	800	1000
		hp required(3)								
50	116	3.9	7.8	11.7	16	20	23	27	31	39
55	128	4.3	8.7	13	17	22	26	30	35	43
60	140	4.7	9.5	14	19	24	28	33	38	47
65	151	5.1	10	15	20	25	30	36	41	51
70	162	5.5	11	16	22	27	33	38	44	55
75	173	5.8	12	17	23	29	35	41	47	58
80	185	6.2	12	19	25	31	37	44	50	62

Nozzle wear: How far gone are your sprinkler nozzles?

With heavy nozzle wear, your pump can be using about 10 to 20 percent more energy to keep up the water pressure. That translates into bigger fuel bills and more water put on than you need.

One easy way to check for worn sprinkler nozzles is to stick the shank of a drill bit the same size as a nozzle rating with the system running. If the nozzle is worn, water will spray out as follows:

Slight wear. . . . . sprays 5 to 8 feet
Moderate wear . . . . . sprays 10 to 15 feet with slight streams
Heavy wear . . . . . sprays 10 to 15 feet with strong streams

Screen out debris

Unless your water comes from a well, it is likely to carry debris that can clog the small sprinkler nozzles. To catch the debris, use a screen with openings slightly smaller than the sprinkler size. The screen can be a commercial cone screen used on the pressure side of the pump. Or, use a home built screen box and put the suction hose into it. Either type needs cleaning from time to time.

Preparing the seedbed for sprinkler irrigation

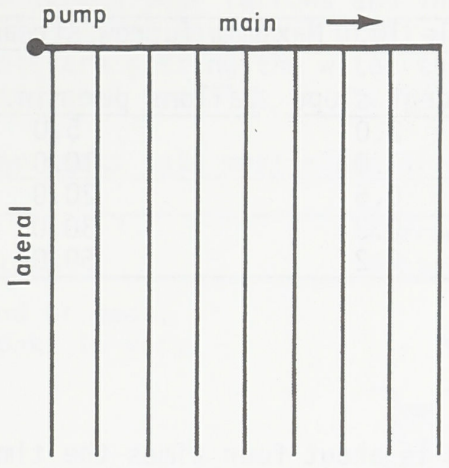
When sprinkling, it's more important to have a well prepared seedbed--with small clods--than with furrow irrigation. (Large clods won't "melt" with sprinkler irrigation.)

(1) CFS--The flow of water to the next larger 1/2 cfs that must be ordered from the water district, assuming the district accepts orders only in increments of 1/2 cfs. Actually 1/2 cfs equals 225 gpm.
(2) Including nozzle pressure, friction loss, and elevation lift.
(3) Pump assumed to operate at 75 percent efficiency.

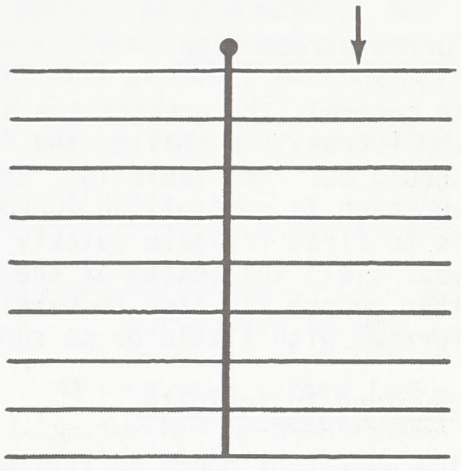
Placement of sprinkler pipe

If you put the pipe down to irrigate the whole field at the same time (solid set) you'll have two basic ways to lay out pipe. With the second method, less pressure is lost at the far ends, so irrigation is more uniform.

First method

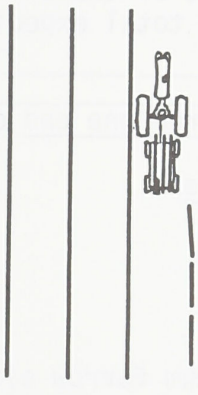


Second method

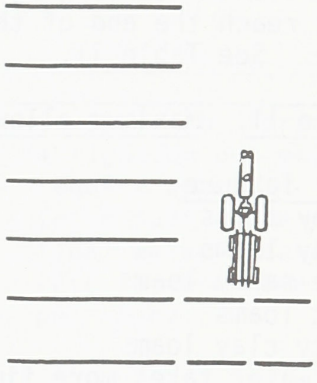


Laying down the irrigation pipes

Spreading pipe in furrows with trailer



Spreading pipe across beds with trailer



When spacing is, for instance 30x40 feet, wind doesn't disturb water distribution as much if the closer spacing runs at right angles to the prevailing winds. (This is assuming you are using the usual rectangular sprinkler spacings.) To do this, pipes can be laid across beds if needed to make sprinkling more uniform to the wind.

FURROW IRRIGATION

Wide furrows vs. narrow furrows

Each furrow width has pros and cons. Broad, wide furrows are especially good for soils that don't take in water well. Wide furrows, especially when roughened or furrowed out, slow the speed of the stream and allow more time for water to soak in. Wide furrows are useful for land with slightly too much slope. Unfortunately, wide furrows may also result in wetter beds and more rots or other crop diseases if used on fields that don't need them.

How much should furrows slope?

The more uniform the slope from one end of the irrigation run to the other, the more uniform the water distribution. The preferred slope for most row crops is less than one percent.

Furrow stream size

In general, the greater the slope along the furrow, the smaller the furrow stream should be. See Table 10. The best approach to controlling furrow size is to first irrigate quickly to wet your field the length of the furrows; then reduce the flow to barely wet furrows with little or no runoff.

Table 10. Maximum furrow stream size.

Percent slope	Gallons per min. per furrow
2.0	5.0
1.0	10.0
0.5	20.0
0.3	30.0
0.2	50.0

How long to irrigate

The number of hours to furrow irrigate a field is about four times the time it takes to wet the furrows. So, if it takes two hours to reach the end of your furrows, with reduced flow the total irrigation time should be about eight hours. To prevent waterlogging of soils, the reverse "rule of thumb" is true. Water must reach the end of the furrows in one fourth the total expected irrigation time. See Table 11.

Table 11. Maximum allowable time for water to go from one end of field to other.

Soil Texture	Hours
Loamy sands	2-3
Sandy loams	3-4
Fine sandy loams	4-5
Silt loams	5-6
Silty clay loams	6-7

(If water takes more time than shown with the maximum furrow size, shorten the length of the run.)

Table 12. Maximum recommended furrow lengths(1)

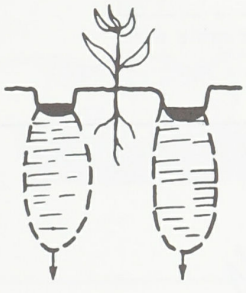
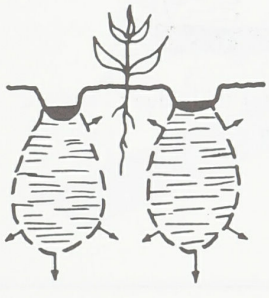
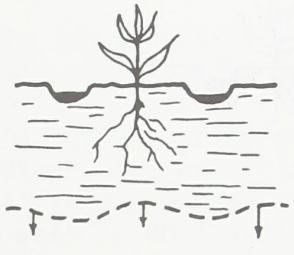
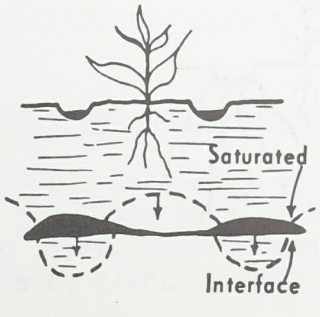
Water intake rate	Probable soil texture	Maximum furrow length(2)
High (1 to 3 inches per hour)	Sandy, clay, sandy clay loam	660
Medium (1/2 to 1 inch per hour)	Loam, silt loam	1,320
Medium low (1/2 to 1/4 inch)	Clay, clay loam, silty clay loam	2,640
Low (1/4 or less inch per hour)	Clay	2,640

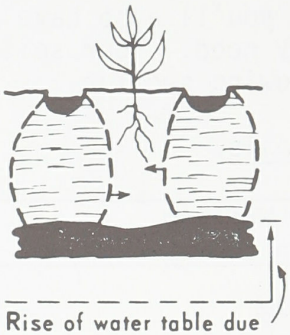
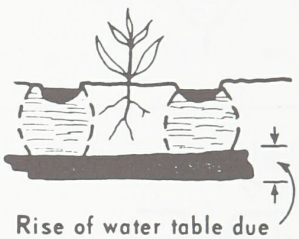
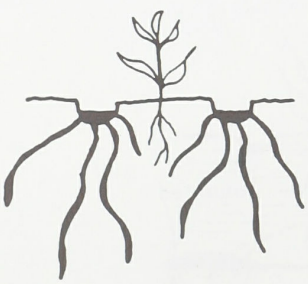
(1) Does not apply to fields with slopes over 0.5 percent.
(2) Irrigation runs should not exceed 600 feet on sandy soils and about 1,300 feet on clayey soils.

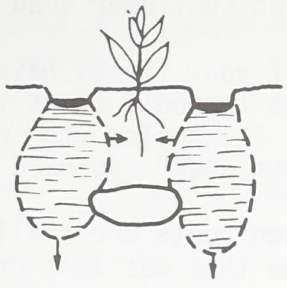
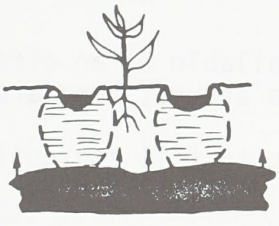
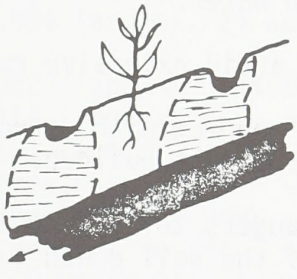
After irrigating: did the water go where you wanted it to?

For routine checks on soil moisture penetration, you can use a shovel, soil probe, and tensiometers about one third in from each end of the field. To get a better idea of whether irrigation water is soaking to where you want it, occasionally dig a trench across your furrows and inspect the wetting pattern of the water. Not only will you see your soil profile, you'll also have a clearer picture of how well roots are getting the water they need. Your soil will probably look much like one of the soil profiles in the following section.

How water soaks into most kinds of soils.

Profile Description	Furrow Wetting Pattern	Remarks
Deep sand or peat, water soaks in very fast.		Not enough lateral movement of moisture to make furrow irrigation feasible.
Deep sandy clay or loam, water soaks in fast. Final water intake rate 1/2" to 3" per hr.		Suitable for furrow irrigation but may require special techniques where the final water intake rate is more than 1" per hour.
Deep clay or loam. Takes water in at 1/4" to 1" per hr.		Ideal for furrow irrigation.
Slowly permeable soil on top; (eg. clay). Water runs quickly through subsoil (coarse sand, etc.)		More water may be stored in this soil than might be expected. Abrupt soil change slows downward water movement and increases storage of water for plants.

Profile Description	Furrow Wetting Pattern	Remarks
	 Rise of water table due to irrigation.	Unsuitable for irrigating row crops. Artificial drainage may be a solution. Loam or clay top soil could contain salts. Permanent water table within 6' to 8' of surface. Poor drainage.
	 Rise of water table due to irrigation.	Exceedingly hazardous to furrow irrigate. Slight rise in water table may cause concentration of harmful salts at ground surface. Less than 3' to 4' of top soil is loam or clay soil that could contain salts. Permanent water table is a few inches below in poorly drained sand or gravel.
Exceedingly tight, deep soil. Water intake rate is 1/10" to 1/4" per hour.		Not enough water penetration for good irrigation. Possible exception is when continuously flooded for rice growing.
Tight, deep soil. Cracks allow enough water in to meet crop needs		Cracks make possible deep wetting of the soil.

Profile Description	Furrow Wetting Pattern	Remarks
Deep soil with underground sand or gravel streaks.		All or parts of the row may not get enough water. Deep subsoiling may remedy the trouble.
Top soil could contain salts Soil underneath is tight and doesn't drain.		Nonirrigable (except for rice) unless subsurface drainage can be provided.
Same as previous picture except slope gives drainage.		Often suitable for furrow irrigation.

DRIP IRRIGATION

Drip tubing or tape is the main low pressure trickle system used on vegetables. It is available at most farm supply stores. The tubing is usually buried two to six inches deep in the beds. Drip tubing (tape) almost universally emits 0.6 gallons per minute for each 100 feet of tubing. Some new low flow tubing is available at .35 gal/min/foot. In cool weather, the equivalent of one hour per day of irrigation with normal hi-flow tubing will supply enough water for most vegetables. Most growers irrigate two or three times a week in cool weather for two to four hours each time. In warm weather with maturing crops, you will need twice as much watering time. That translates into four to eight hours at each irrigation, two to three times a week. This schedule is for single row crops with one tube below or beside each row. If you put one tube below and beside two crop rows, your water requirements will be about doubled.

IRRIGATING HARDPANS, CLAYPANS, AND COMPACTED SOILS

If you have shallow soil above a hardpan or claypan, and it's too thick to be penetrated by a ripper or slip plow, you have to irrigate cautiously. If you irrigate deeper than the restricting layer, roots drown out from Phytophthora or other root rot. If you irrigate too late, plants suffer because they can't get enough water from shallow soil.

You can try to correct the problem with tillage. Otherwise, you will have to farm the field as if the crop's root system is only as deep as the impervious layer. This means irrigating more often and shallower than with deeper soils.

A similar approach is called for if your fields have been compacted. For example, if you worked the soil while it was too wet, check for a shallow root system due to compaction. If the root system is shallow (for whatever reason), you will need to consider the "more often but less deep" approach to irrigation.

Another method some growers use when roots are shallow is irrigating every other row. Then they irrigate the furrow that was left dry several days later. This cuts losses if Phytophthora or drown out is a problem.

SAVING ON THE WATER BILL

Some years not enough water is available at an affordable price. If you don't have enough irrigation water to go around, here are some useful ways to save water:

1. Pre-irrigate in early spring to fill the soil profile throughout the expected root depth.

2. Fertile fields are most efficient in using water. Rather than trying to stretch water over too many acres, farm only the fertile fields.

3. Control weeds. They use up water.

4. Shorten irrigation runs to avoid excessive runoff.

5. Every other row irrigation coupled with narrow or split beds can cut down both water use and in-the-row salt buildup.

6. Use tensiometers and soil augers to help decide when to irrigate. Don't irrigate by the calendar if the soil doesn't need water.

7. During cool weather, delay irrigation.

8. Laser beam grading and planing may be needed to assure uniform application of water.

9. Large amounts of water are wasted on pumping costs for well water. This is because electric pumps are not always kept repaired. While electric pumps are not cheap to repair, pumping costs of letting them go cost more. It is recommended that pumps be repaired when 200 kwh are required to lift one acre-foot 100 feet.

10. A tail water reuse system may be needed. A reuse system pumps tail water back to the head end, or to another field. Efficiencies of 87 to 92 percent have been achieved with surface irrigation using gated pipe and reuse systems.

APPENDIX: LIST OF EQUIVALENTS

The following equivalents may be used for converting from one unit to another and for computing volumes from flow units:

Volume units

One acre-inch = 3,630 cubic feet
27,154 gallons
1/12 acre-foot

One cubic foot = 1,728 cubic inches
7,481 (approx. 7.5) gallons
weighs approx. 62.4 pounds
(62.5 for ordinary calculations)

One acre-foot = 43,560 cubic feet
325,851 gallons
12 acre-inches

One gallon = 231 cubic inches
0.13368 cubic foot
weighs approx. 8.33 pounds

Rate of flow units

One cubic foot per second = 448.83 (approx. 450 gallons per minute)
50 So. Calif. miner's inches
40 Calif. statutory miner's inches
1 acre-inch in 1 hour 30 seconds (approx. 1 hour), or
0.992 (approx. 1) acre-inch per hour
1 acre-foot in 12 hours 6 minutes (approx. 12 hours), or
1.984 (approx. 2) acre-feet per day (24 hours)

One gallon per minute = 0.00223 (approx. 1/450) cubic foot per second
0.1114 (approx. 1/9) So. Calif. miner's inch
0.0891 (approx. 1/11) Calif. statutory miner's inch
1 acre-inch in 452.6 (approx. 450) hours, or 0.00221 acre-inch per hour
1 acre-foot in 226.3 days, or 0.00442 acre-foot per day
1 inch depth of water over 96.3 square feet in 1 hour

Millions gallons per day = 1.547 cubic feet per second
694.4 gallons per minute
77.36 So. Calif. miner's inches
61.89 Calif. statutory miner's inches

One So. Calif. miner's inch = 0.02 (1/50) cubic foot per second
8.89 (approx. 9) gallons per minute
0.80 (4/5) Calif. statutory miner's inch
1 acre-inch in 50 hours and 25 minutes, or 0.0198 (approx. 1/50) acre-inch per hour
1 acre-foot in 605 hours (approx. 25 days) or 0.0397 (approx. 1/25) acre-foot per day

One Calif. statutory miner's inch = 0.025 (1/40) cubic foot per second
11.22 (approx. 11-1/4) gallons per minute
1.25 So. Calif. miner's inches
1 acre-inch in 40 hours 20 minutes, or 0.0248 (approx. 1/40) acre-inch per hour
1 acre-foot in 484 hours (approx. 20 days), or 0.0496 (approx. 1/20) acre-foot per day

Conversion table for units of flow.

	Cubic feet per second	Gallons per minute	Million gallons per day	So.Cal. miner's inch	Calif. statutory miner's inch	Acre-inches per 24 hours	Acre-feet per 24 hours
Cubic feet per second	1.0	448.8	0.646	50.0	40.0	23.80	1.984
Gallons per minute	0.00222	1.0	0.00144	0.1114	0.0891	0.053	0.00442
Million gallons per day	1.547	694.4	1.0	77.36	61.89	36.84	3.07
So. Cal. miner's inches	0.020	8.98	0.0129	1.0	0.80	0.476	0.0397
Cal. stat. miner's inches	0.025	11.22	0.0162	1.25	1.0	0.595	0.0496
Acre-inches per 24 hrs.	0.042	18.86	0.0271	2.10	1.68	1.0	0.0833
Acre-feet per 24 hrs.	0.504	226.3	0.3259	25.21	20.17	12.0	1.0

The following approx. formulas may be conveniently used to compute the depth of water applied to a field:

$$\frac{\text{cu. ft. per sec. x hours}}{\text{acres}} = \text{acre-inches per acre, or average depth in inches}$$

$$\frac{\text{gal. per min. x hours}}{450 \text{ x acres}} = \text{acre-inches per acre, or average depth in inches}$$

$$\frac{\text{So. Cal. miner's inches x hours}}{50 \text{ x acres}} = \text{acre-inches per acre, or average depth in inches}$$

$$\frac{\text{Cal. stat. miner's inches x hours}}{40 \text{ x acres}} = \text{acre-inches per acre, or average depth in inches}$$

Area equivalents.

1 hectare = 2.471 acres
10,000 square miles
107,640 square miles

1 acre = 0.405 hectare
4,046.8 square meters
4,840 square yards
43,560 square feet
160 square rods

1 square mile = 259.2 hectares
640 acres

Linear equivalents.

1 meter = 39.37 inches
1.094 yards

1 inch = 2.54 centimeters

1 yard = 36 inches
3 feet
.914 meters

1 rod = 5.029 meters
5.50 yards
16.5 feet

1 mile = 5,280 feet
329 rods