8

Irrigating and Mulching*

IRRIGATING

For vegetable crops to grow successfully, large quantities of water, either as rain or as irrigation, are needed. Unfortunately, in most areas in the United States where vegetables are grown, rainfall is either inadequate or too inconsistent for optimum vegetable production. Many regions may receive adequate rainfall during the year, but the rain does not occur when crops need it the most.

Irrigation is the only reliable means of assuring adequate water supply for successful commercial vegetable production. All vegetables in California, Arizona, and New Mexico are irrigated in some form or fashion, and a large percentage of crops grown in other western states are fully or partly irrigated. Not only is irrigation important in arid and semi-arid regions, but it is also important in humid regions. With the high costs of production, growers cannot afford losses in crop quality or yields due to insufficient water.

WATER REQUIREMENTS

During the production of a crop, water is lost from plants mostly from transpiration and by evaporation from soil and accumulations on plant surfaces. The sum of these losses is called *evapotranspiration*, and together with the water retained by the plant (about 85 to 96 percent of the total plant weight), makes up the consumptive water use. For some crops, up to 400 to 600 pounds of water will be required to produce 1 pound of dry matter.

*This chapter co-authored by W. H. Shoemaker, Horticulturist, University of Illinois

A crop's water requirement may also include water expended for other purposes, including leaching, frost protection, crop cooling, seed germination, and other reasons. Part of this water can be supplied by water previously stored in the soil, growing season precipitation, and groundwater within reach of the roots. Water that is not supplied by any of these sources must be supplied from irrigation during the growing season. For example, in the San Joaquin Valley of California it may take up to 23 gallons of irrigation water to produce 1 pound of lettuce, 33 gallons for 1 pound of carrots, 39 gallons for 1 pound of cucumbers, 61 gallons for 1 pound of spinach, 51 gallons for 1 pound of muskmelons, and 122 gallons for 1 pound of sweet corn on the cob.

The water requirement for most crops is affected by many natural and management factors. Natural factors include soils, topography, and climate (temperature, precipitation, solar radiation, and wind). Management factors include water supply, water quality, planting date, crop species and cultivar, irrigation scheduling, fertility, plant spacing, cultivation, and pest control. Plant species and cultivar determine rooting depth and length of growing season. Management factors can usually be controlled, although many are interrelated with natural factors.

Critical Periods of Water Use

Vegetables require a fairly constant supply of soil moisture throughout the growing season. Water stress early in their production can delay maturity and reduce yields. Water shortages later in the growing season, especially during maturation, can severely decrease quality, even though yields may not be affected.

In general, vegetables grown for their foliage require uniform moisture throughout their development, while those grown for fruits and seed require the largest amounts during fruit set and maturation (Table 8.1). Root, tuber, and bulb crops need water the most during the period of enlargement of these parts. The same holds true for plants such as cabbage and lettuce that develop heads. For solanaceous crops (tomatoes, peppers, and eggplants) and cucurbits (melons, cucumbers, squashes, and pumpkins), water stress during anthesis can result in poor pollination, which can severely reduce fruit yield and quality. Moisture stress or moisture fluctuations during fruit development may cause fruits to crack. Crops such as beans, peas, and corn, which are grown for their fresh or dry seeds, pods, or ears, need adequate moisture at the time of flowering (or tasseling), fruit set, and fruit development. Moisture stress during anthesis can cause flowers to abort in beans and peas and

Table 8.1. Critical Periods of Water Use in Vegetable Crops

Crop	Critical Period
Broccoli, cabbage, cauliflower, lettuce	Head development
Beets, carrots, radishes, turnips	Root enlargement
Sweet corn	Tasseling and ear development
Cucumbers, eggplants, melons, peppers, tomatoes	Flowering, fruit set, and fruit enlargement
Beans, peas	Flowering and pod development
Onions	Bulb development
Potatoes	Tuber initiation and tuber enlargement
Asparagus	Fern development

can result in incomplete tipfill in sweet corn from inadequate pollination. During fruit development, water stress can cause malformed pods and ears.

Bad timing or too much irrigation can reduce yields and quality. Excessive moisture in combination with high nitrogen levels can overstimulate vegetative growth in solanaceous crops and cucurbits, severely delaying maturity. For processing crops such as pumpkins and potatoes, excessive amounts of water late in the season can decrease total solids and dry matter in fruits and tubers, resulting in poor quality and low product recovery.

Soil Moisture

For determining the amount and frequency of irrigation, the soil type, texture, and depth should be checked, since this information is used to ascertain the soil water-holding capacity or field capacity (FC). This is the quantity of water that the soil will hold against the pull of gravity and represents the upper limit of available water. The difference between the actual available moisture in the soil and the FC indicates how much water to supply. The actual available soil moisture can sometimes be estimated by feel but can be more precisely determined by instruments such as tensionmeters, neutron probes, or meters for measuring electrical resistance.

Measurement of soil moisture levels, however, provides only indirect measurements of plant water status. Generally, irrigation should begin when 40 percent of the FC is removed from fine-textured soils, and 60 percent is removed from sandy soils. There should be no delay in supplying water. Research and experience show that with many crops a damaging water shortage may exist before the plants exhibit outward signs of water stress.

Water Frequency and Amount

The frequency of water application depends on the total supply of available moisture to the roots and the rate of water use, which is influenced by factors such as rainfall, plant age, rooting depth, soil type, and rate of evapotranspiration; the latter depends on crop cover, temperature, humidity, and wind. For most vegetables in humid regions, from 1 to 2 inches of water per week is needed during their active growing season. However, under hot, dry, windy conditions, 2 to 3 inches of water may be needed per week. In arid regions, vegetables may require up to 4 inches of water per week.

When plants are young, the rate of water use is low. Later in the season, as the crop canopy size increases, daily water use increases because there is more transpirational surface from growth, but the depth of rooting is also greater. Generally, less frequent irrigations will be needed later in the season, but at each irrigation, more water will be required. Light, frequent irrigations are usually not recommended, except at the early seedling stage, when the plant has a limited root system.

A consumptive water-use curve for dry bulb onions grown in Arizona is presented in Figure 8.1. The figure contains estimates of seasonal use (23.3

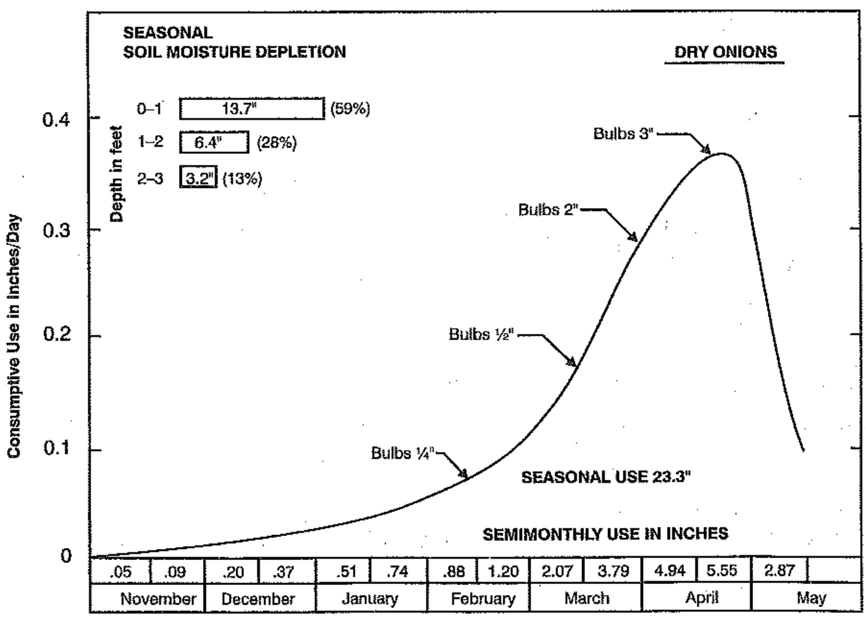

Figure 8.1. Mean consumptive water use for dry bulb onions at Mesa, Arizona. (Source: Erie, L. J., O. F. French, D. A. Bucks, and K. Harris. 1982. Consumptive Use of Water by Major Crops in Southwestern United States. USDA ARS Consv. Res. Rpt. No. 29)

inches), semi-monthly use, and soil moisture depletion. Peak water-use rate occurs during the period when the bulb increases in size from 0.25 to 3 inches. Seasonal moisture depletion in the soil down to 3 feet is shown by bar graphs in the upper lefthand corner of the figure.

Rooting depth is an important factor affecting the crop's water requirement and the frequency of irrigation. Not only does it determine the depth of the soil profile that roots can utilize as a water source, but it also influences the irrigation depth. Vegetables such as celery, lettuce, potatoes, and sweet corn are shallow-rooted, and it is necessary to keep the available soil moisture in the surface foot of soil, especially for the first part of the growing season. Onions are very shallow-rooted, and available water must be maintained in the surface 6 to 12 inches throughout the growing season.

Water requirements per irrigation application for shallow-rooted crops are small, but the frequency of application may be high. Shallow-rooted vegetables should not go more than 4 to 6 days without water, either as rainfall or irrigation, in sandy soils, and 10 to 12 days in clay soils (Table 8.2). Deep-rooted vegetables such as tomatoes and melons require less frequent irrigations, but more water is needed at each irrigation. When applying water, the grower should add enough to increase the soil moisture content in the rooting zone to field capacity.

Table 8.2. Relative Frequency and Amount of Irrigation Water for Vegetable Crops as Affected by Soil Type and Rooting Depth (for summer conditions, Davis, California)

	Sandy Soil		Loam Soil		Clay Soil	
Rooting Depth	Irrigation Interval	Application Rate	Irrigation Interval	Application Rate	Irrigation Interval	Application Rate
	(days)	*(in.)*	*(days)*	*(in.)*	*(days)*	*(in.)*
Shallow (0–2 ft.)	4–6	1–2	7–10	2–3	10–12	3–4
Medium (0–4 ft.)	7–10	2–3	10–15	3–4	15–20	4–5
Deep (0–6 ft.)	10–12	3–4	20–30	4–5	30	5–6

As discussed, water requirements for vegetable crops are likely to vary, depending on natural and management factors. However, for maximum production, a crop requires a fairly definite amount of water during the growing season. Table 8.3 presents information on water requirements in selected vegetable crops according to rooting depth.

Table 8.3. Depth of Rooting and Amount of Irrigation Water Needed for Vegetable Crops in California[a]

Rooting Depth	Water Needed for Crop (in.)			
	12	12–17	18–24	30–40
Shallow (<2 ft.)	Lettuce (winter) Spinach	Broccoli Brussels sprouts Cabbage Cauliflower Onions (early)	Lettuce Potatoes Onions (late) Sweet corn	Celery Potatoes (summer)
Medium (2–4 ft.)	Peas (winter)	Cucumbers Pole beans Snap beans Turnips	Beets Carrots Eggplants Peas (fall) Peppers Summer squash	
Deep (4 ft. or more) . . .		Artichokes Lima beans Watermelons	Asparagus Muskmelons Parsnips Pumpkins Winter squash Sweet potatoes Tomatoes	

[a]Source: Doneen, L. D., and J. H. Macgillivray. *Suggestions for Irrigating Commercial Truck Crops.* Univ. of California Agric. Exp. Sta. Leaf. 9938.

IRRIGATION METHODS

Surface Irrigation

Surface irrigation, as the name implies, is the practice of spreading water over the surface of the land. Two systems—flood irrigation and furrow irrigation—are common. In flood irrigation, water is released into fields that are very level, with only slight contour, and which have border ridges of soil to contain the water. Usually, a thorough saturation (3 to 4 inches) is applied, reducing the number of required irrigations. Salts, which can accumulate on the surface, are leached into the subsoil, making this method well suited for arid regions.

With furrow irrigation the crops are grown on beds with furrows (6 to 8 inches deep) between them (Figure 8.2). Water is allowed to flow down the furrows, from either supply ditches or portable pipe. This method is more suitable than flood irrigation in fields that are not level, provided they have a constant slope. A modification of furrow irrigation, known as surge irrigation, was developed in the 1980s. Using portable pipe with electronically controlled gates, water is allowed to flow down alternate rows only as far as it can be uniformly applied. Then the other row is irrigated. As the first row soaks up water, the soil surface closes up, allowing the next surge of water to pass. The result is more uniformity of water application between the beginning and end of the furrow.

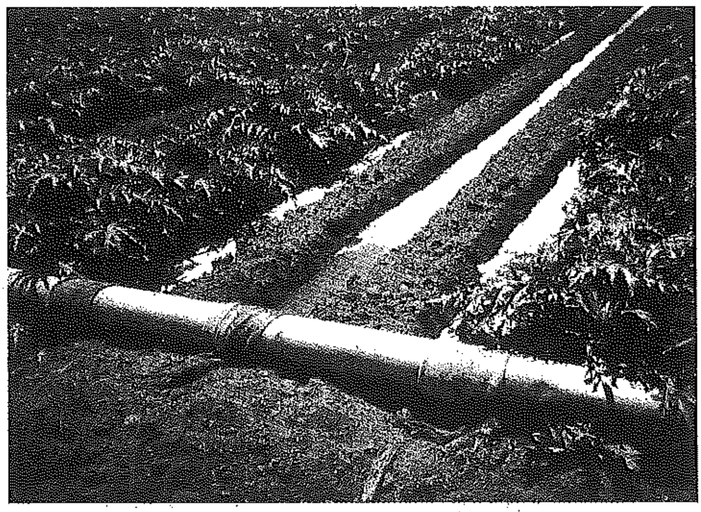

Figure 8.2. Sprinkler irrigation is generally more efficient than furrow irrigation, though the furrow system still remains the most economical and most widely used in western growing areas.

When the initial cost of wells, pumps, and other equipment is not so large, surface irrigation requires only a modest investment. If the supply of water is limited, this method is well adapted to irrigating large areas, since water loss from evaporation is considerably less than in some other systems. Among the disadvantages are the necessity for constant attention, the tendency for soils to crust, and the large loss of water by seepage in supply ditches.

Sprinkler Irrigation

Approximately 33 percent of irrigated ground in the United States is sprinkler-irrigated. Several different systems are used, including center-pivot and linear-move systems, traveling guns, portable pipe, solid-set pipe, and wheel-roll systems. In all of these, water under pressure is dispersed above the ground.

Center-pivot and linear-move systems are characterized by having a main water line that is carried on top of mobile towers (Figure 8.3). Nozzles to disperse the water are evenly spaced along the main conduit, often at the end of drops. With center pivots, one end of the main is stationary and the main turns around the pivot point, similar to the hands of a clock. Linear-move systems simply advance the main at an even pace across the field in a swath pattern. Both can irrigate large areas with a single pass and are best suited for large fields with no more than three or four crops. However, maintenance demands are considerable.

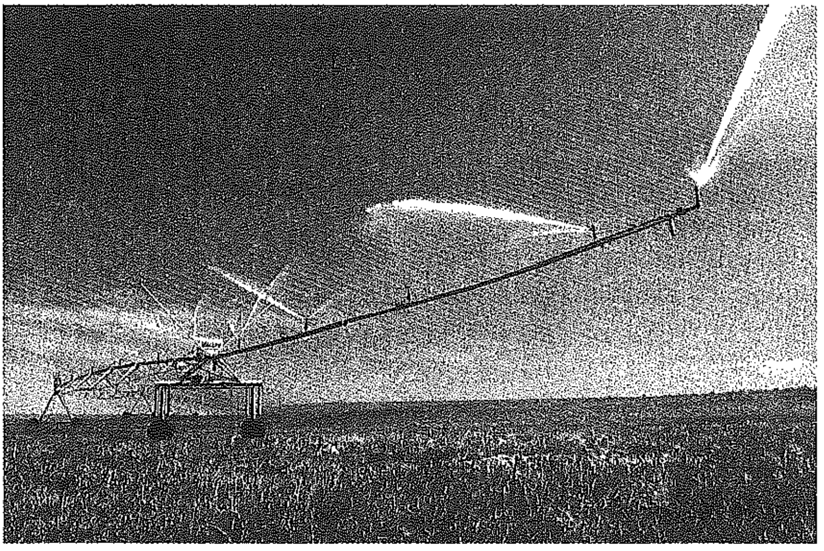

Figure 8.3. Center-pivot systems can range in size, covering from 20 acres to over 100 acres. (Photo: courtesy of Valmont Industries, Valley, Nebraska)

Traveling guns resemble large sprinkler nozzles on a rolling cart. Water is carried to the gun by a hose and pumped through a reel, which winds up the hose as the water is being applied. The guns can wet a pattern of up to 600 feet in diameter. The system is well suited to fields that are long and narrow or irregular in shape, as well as to small operations. The main drawback is the low efficiency of application. However, the low initial cost of the system makes it a reasonable option in some cases.

Portable pipe and solid-set pipe consist of a pipe system laid out in the field to carry water to a grid of sprinklers. A solid-set system is permanently installed, whereas a portable pipe system is temporary and can be moved or rearranged at any time. Solid-set systems are generally limited to perennial crops because they can be a serious impediment to cultural operations. However, they can reduce labor inputs if a cultural system can be devised around it. Portable pipe is usually made of a light-gauge aluminum, from 2 to 12 inches in diameter, with risers and sprinklers at each joint. It is labor-intensive but can be rearranged and easily moved. About one worker-hour per acre is required for a portable pipe system, compared to about 10 to 15 percent as much labor for most mechanically moved systems. If labor is not a problem, portable pipe is the most flexible of sprinkler systems.

Wheel-roll systems are used more often in sod production but can be used in vegetables. A pipe with sprinklers is mounted on wheels, which carries it through the field, applying water as it goes. A hose carries water from a main to the system. This system is restricted by the height of the plants and works best with short crops.

Sometimes a combination of systems may be used. In the Southwest, growers often use portable pipe sprinkler irrigation to germinate lettuce. The wet soil provides a softened soil cap, which is easily penetrated by the small seeds during germination. The sprinkler irrigation also has a cooling effect on the soil, increasing seed germination under high temperatures. After the crop has emerged and is growing well, irrigation is changed to the traditional furrow method.

Trickle (Drip) Irrigation

Trickle or drip irrigation is characterized by operation under low-pressure (6 to 20 psi), point-source application, slow application, and high efficiency. Water is carried through plastic tubes or tapes and released through emitters that regulate the amount and rate of water applied (Figure 8.4). The slow rate of application accommodates infiltration rates, increasing efficiency. Because of the low pressure and volume, operating costs are reduced. Other advantages include: (1) the ability to fertilize or apply pest control materials through the system, (2) irrigation of crops during cultural operations, (3) no wetting of plant material, (4) adaptation of automated control systems, and (5) greater ease of coordinating foliar pest control with irrigation schedules. Some disadvantages of this method include a tendency for emitters to become clogged with debris and algal and fungal growth, and a possible salt buildup around the perimeter of wetting patterns in arid climates. The cost of installation and material is moderate, but it is higher than for conventional furrow irrigation.

Two major types of drip systems—lightweight tapes and heavy-gauge tubing—are available. The plastic tape is approximately one-third the cost of the

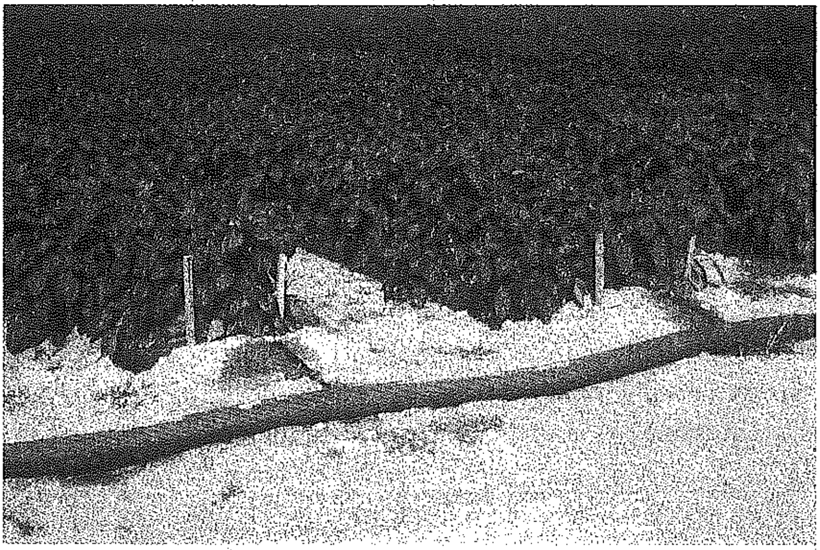

Figure 8.4. Plastic trickle (drip) irrigation lines in bell peppers.

tubing but does not last as long. Either can be laid on the surface or buried, which facilitates cultural practices and increases longevity.

Trickle systems have been used successfully for years in arid regions but are also feasible in many humid areas and in home gardens. Recent research in south Texas has shown trickle irrigation to increase yields of tomatoes, peppers, onions, muskmelons, and watermelons by 15 to 25 percent, and with water savings of more than 50 percent, compared to conventional furrow irrigation.

Subirrigation

In subirrigation, water is added in such a way that it permeates the soil from below. Subirrigation requires an abundance of water, a sandy loam topsoil through which water will move freely by capillary attraction, and an impervious subsoil that will hold the water. At the same time, adequate drainage is necessary. The large amount of water required and the great expense involved in the laying of tile pipes (if any such structures are needed) are disadvantages. Advantages include the maintenance of an undisturbed soil mulch and lack of trouble from soil baking. In actual practice, subirrigation is sometimes difficult, justifying considerable investigation of existing soil conditions and the water supply before such a system is installed.

SOURCES OF WATER

Water for irrigation may be obtained from streams, lakes, wells, springs, winter-runoff, and municipal sources. Virtually all states have laws and regulations pertaining to the use of water for irrigation. These should be known and understood before any irrigation system is designed. Local state water conservation offices can be of assistance.

In the past, when water was obtained from flowing wells or springs, or diverted from streams and lakes, the costs of water application were relatively low. While this is still true for many areas of the East and Southeast, the situation has changed considerably in other regions of the United States. In the West and Southwest, the expense of applying water to the land has increased dramatically. In recent years, the costs of irrigating vegetable crops in the Sacramento and San Joaquin valleys of California have tripled, going from $160 an acre for 2 acre-feet of water to more than $400 an acre (note: an acre-foot is approximately 326,000 gallons). This is due in large part to urban competition for water sources and to inconsistent rainfall in northern California where winter mountain snows supply the water to southern growing areas.

When powerful pumps are required to raise the water, initial expenses are high. The cost of drilling a well and installing a pump and motor, as well as building a reservoir for temporary storage, can amount to a substantial investment. If water has to pumped uphill to the field, the costs can double what a gravity-feed would cost.

Water Quality

The agricultural suitability or quality of irrigation water for vegetable crops is determined by the concentration and composition of dissolved salts in the water supply. The concentration of salts in the water can increase soil salinity to the point where the osmotic pressure of the soil solution in the root zone makes it very difficult for plants to extract water. Consequently, crops subjected to excessive salt levels show many of the same symptoms as in a drought, including wilting and impaired growth. Vegetables differ considerably in their sensitivity to salts. Crops such as beans, carrots, and onions are very susceptible to high salt levels and will suffer large yield reductions if irrigated with saline (high salt) water. At the other extreme are asparagus, beets, and spinach, which are tolerant of salts and can be successfully grown when saline water is used for irrigation.

There are several elements found in natural waters that can be toxic to plants, with the most common ones being chloride, sodium, and boron. Leaf burn caused by sodium and chloride may occur in some crops with sprinkler irrigation when the humidity is low and the evaporation rate is high. Beans, onions, and Jerusalem artichokes are highly sensitive to boron and will experience significant yield reductions if boron concentrations exceed 1 ppm in irrigation waters. In contrast, asparagus and beets are tolerant of boron and will grow quite well at relatively high boron levels in the water supply.

Problems with water quality are usually less in humid climates than in arid and semi-arid regions, where high concentrations of dissolved ions and salts frequently occur in water used for irrigation. Depending on water management practices, environmental conditions, and species tolerances, these could become toxic to plant growth. For most vegetable production, irrigation water with a salinity content less than 480 ppm (total dissolved solids), sodium below 3.0 SAR (adjusted sodium adsorption ratio), boron less than 1 ppm, and chloride below 100 ppm, would be considered excellent (Table 8.4).

Other components of water quality include bicarbonate, nitrate, and pH. Bicarbonate ions in water can be a problem in some areas, primarily from their adverse effect on soil permeability. With overhead sprinkler irrigation, a white deposit of calcium carbonate may form on the leaves and fruit. Although this is not detrimental to plant growth, it can render harvested

Table 8.4. Qualitative Classification of Irrigation Water[a]

	Water-Quality Problems		
	None	Increasing	Severe
Salinity			
TDS (ppm)[b]	Less than 480	480–1,920	More than 1,920
Boron (ppm)	1.0	1.0–2.0	2.0–10.0
Sodium (adj SAR, ppm)[b]			
Root absorption	Less than 3.0	3.0–9.0	More than 9.0
Foliar applied	Less than 70	70	—
Chloride (ppm)			
Root absorption	Less than 70	70–345	More than 345
Foliar applied	Less than 100	100	—
Bicarbonate (ppm)	Less than 40	40–520	More than 520
pH	6.5–8.3	More than 8.3	—

[a]Source: Farnham, D. S., R. F. Hasek, and J. L. Paul. 1985. *Water Quality*. University of California Div. Agric. Sci. Leaf. 2995.

[b]TDS (total dissolved solids), SAR (sodium adsorption ratio).

crops unattractive, and in some cases unmarketable. In some areas, high nitrate concentrations in irrigation water are becoming major environmental and consumer health concerns.

Table 8.4 outlines some water quality guidelines for vegetable production. Some flexibility should be considered, depending on crop, soil characteristics, irrigation methods, and local climate.

MULCHING

Mulching vegetable crops to improve growing conditions is a time-honored practice that goes back to early agriculture. In the past, mulches were primarily organic in nature and used mainly to conserve moisture, but in the 1960s, with the introduction of new synthetic plastics, the role of mulches in vegetable production expanded considerably. Today, mulches are also used extensively to hasten maturity and to help control weed growth. In the home garden, mulching can result in more efficient use of space. Whenever mulches are used to improve the plant environment, higher yields generally result.

PRINCIPLES

A mulch is created when the soil surface is artificially modified by a covering of natural or synthetic materials. The purpose of a mulch is to enhance crop growth by changing the plant's soil and air microclimate. This includes soil temperature, moisture, weed competition, soil structure, and biological activity. Vegetable crops usually grow better when mulched because an extensive root system is allowed to develop undisturbed under the protective covering.

Changes in soil temperature and moisture from mulching are usually the most important factors in determining crop response to mulch. Mulches conserve soil moisture by reducing water evaporation from soil by 50 percent or more. They also can increase water for crop use by controlling annual grasses and broadleaf weeds. Mulching modifies soil temperatures; organic and light-colored reflective mulches reduce soil temperatures, while black, gray, and transparent mulches increase soil temperatures. Mulches can also reduce fluctuations of both moisture and temperature in the root environment, which may be as important as these other effects on soil water and temperature.

Generally, the effects of mulching are greatest under adverse weather conditions. Warm-season crops such as tomatoes, peppers, melons, cucumbers, and sweet corn respond most favorably to soil-warming mulches applied early in the season. Even when they do not increase yields, mulches can improve crop quality by keeping fruits clean and free from defects.

MATERIALS

Mulch materials can be grouped into two general categories: natural and synthetic. Commonly used natural materials include plant residues such as straw, leaves, corncobs, peanut hulls, and pine needles; animal manures, peatmoss, and wood products such as bark, wood chips, and sawdust. The most popular synthetic materials are the clear and black polyethylene films. Metal foils, paper, and asphalt mulches have also been used in some situations. Aluminum foil mulch has been used on Chinese cabbage and summer squashes to repel aphids that spread mosaic viruses.

Organic Mulches

The natural or organic mulches reduce soil temperatures and provide excellent moisture control, if applied 2 inches deep or more around crop plants. Organic mulches can improve soil tilth and enhance biological activity as they decompose and can reduce wind and water erosion. However, these materials are bulky and difficult to handle on a large scale, requiring much labor to apply, and are often unavailable in sufficient quantities for most commercial operations. Consequently, most natural mulches are largely restricted to the home garden (see Chapter 30).

Plastic Mulches

The most popular mulches for commercial vegetable operations are the clear and black polyethylene films (Figure 8.5). Growing vegetables for fresh market on plastic-covered beds has become a standard practice in many vegetable areas. Florida has about 100,000 acres of commercial vegetables growing under plastic or other mulch materials.

Because of their ability to increase soil temperatures, it is now standard practice to use clear and black plastic mulches with muskmelons and watermelons, and with early plantings of cucumbers, eggplants, peppers, tomatoes, summer squashes, and sweet corn. Yields are often higher, and harvest may

Figure 8.5. Peppers are being grown on a twin-row bed covered with black plastic mulch.

be 5 to 10 days earlier than with unmulched plantings. Clear plastic will generally warm the soil about 8 to 10°F more than black plastic and should be used for the earliest plantings. However, weeds can grow under clear plastic; thus, herbicides are required. Black plastic prevents light penetration and provides effective weed control. The strips of land between the plastic should be kept free of weeds, either by herbicides or by cultivation. Plastic mulch can also reduce fertilizer losses to leaching, increase fumigant effectiveness, provide for more efficient use of water, and reduce fruit losses to rotting.

The plastic mulch film generally used is 4 feet wide and 1.5 mil (1.5/1000 inch) thick, although various widths are available. The laying of the plastic film is highly mechanized and can be adapted for bed shaping, laying of trickle irrigation tubing, and planting all in one operation (Figure 8.6). The equipment for application of plastic mulch is readily available and relatively simple. Before any mulch is applied, the soil moisture should be near field capacity since this moisture is critical for early growth and cannot be effectively supplied by rain or overhead irrigation to small plants growing under plastic mulch.

One of the main problems associated with plastic mulch is the removal of the material after its use. On small acreages growers manually remove it by running a coulter down the center of the row and picking it up from each side. Commercial removal equipment is also available. Photodegradable plastic films, which break down under ultraviolet light, are available; however,

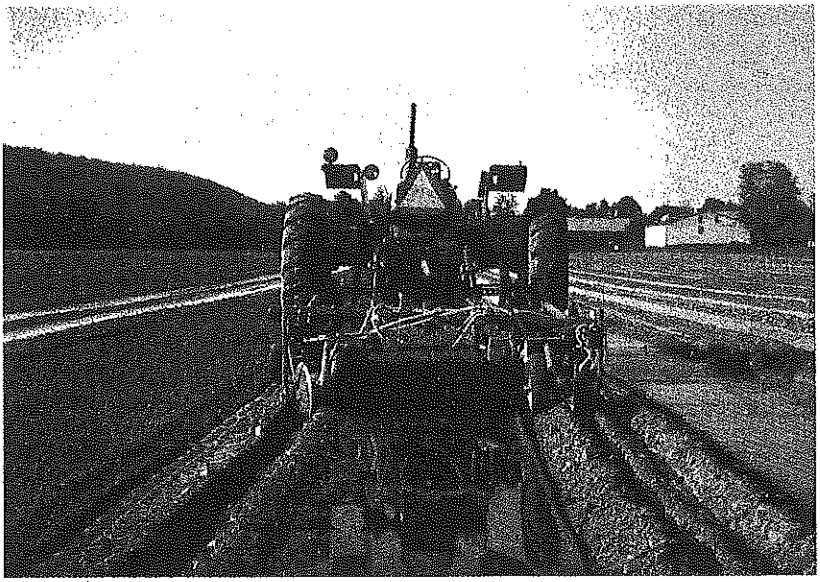

Figure 8.6. Bed shaping and laying black plastic mulch can be done by machine in one operation.

these are more expensive than standard plastic mulch and have not proven completely effective. In some areas, brown paper coated with vegetable oils, such as soybean and linseed, is being used as an alternative to plastic mulches. The paper is biodegradable. Field use has shown the material to have light and temperature properties similar to those of transparent films.

ROW COVERS

A recent development in vegetable production is the use of plastic films or other synthetic materials to cover the crop, creating a greenhouse-like microenvironment around the plant. This practice provides several advantages for vegetable production, including early growth enhancement and earlier maturity, higher yields, insect and wind protection, and in certain situations some frost protection.

The original material was clear or translucent polyethylene film, but polyester, polypropylene, and other polymers are now being used. These new materials may be perforated films; lightweight, porous, spun-bound fibers; or woven materials. When supported, usually by flexible wire hoops placed at 5 to 6 feet intervals in the row, they are called *row tunnels* (Figure 8.7); when applied without any means of support, they are called *floating row covers* (Fig-

Figure 8.7. Row tunnels extend the growing season and make possible early planting of warm-season vegetables.

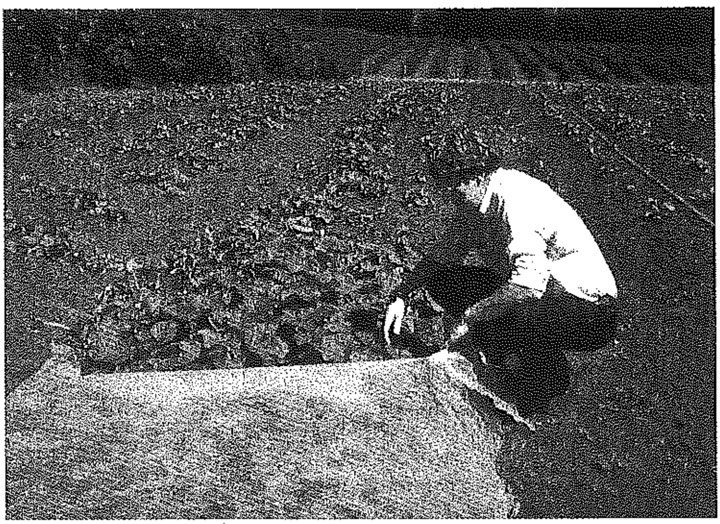

Figure 8.8. Floating row covers made of spunbound polyester are placed on top of muskmelon plants.

ure 8.8). This latter method is more applicable to low-growing vine crops, while the former method is more suited to upright plants, e.g., tomatoes and peppers. Both types are often used in conjunction with plastic mulch. In Europe, field covers are used to cover a number of rows in a single swath.

Acceptance of row covers has not been as rapid as the use of plastic mulch, due largely to problems managing the technique. High air temperatures under the cover can stress the crop, inhibiting growth, inducing bolting, or aborting blossoms. These problems have not been as severe with the translucent materials as with clear plastic. As a result, row covers are always ventilated, but even with slitted air vents, clear plastic has produced heat injury.

Fresh market growers may also use other types of covers to protect their early crops, including "hot caps," which are small, individual paper tents placed

Figure 8.9. Hot caps are placed over individual plants.

over each plant (Figure 8.9). These are then removed when temperatures are favorable and before plant growth becomes confined within the cover.

SELECTED REFERENCES

California Fertilizer Association. 1998. *Western Fertilizer Handbook—Second Horticulture Edition*. Interstate Publishers, Inc., Danville, Illinois.

Erie, L. J., O. F. French, D. A. Bucks, and K. Harris. 1982. *Consumptive Use of Water by Major Crops in the Southwestern United States*. USDA, ARS Conserv. Res. Rpt. No. 29.

Hopen, H. J., and J. W. Courter. 1982. *Mulch for Vegetables*. Univ. of Illinois Coop. Ext. Ser. Hort. Facts VC-20-82.

Kenworthy, A. L. 1972. *Trickle Irrigation: The Concept and Guidelines for Use*. Michigan State Univ. Agric. Exp. Sta. Res. Rpt. 165.

Mansour, N. S. 1989. Using row and field covers on sweet corn and direct-seeded vegetables. In: *Proc. 1989 Illinois Fruit, Vegetable and Irrigation Conv*. Univ. of Illinois Coop. Ext. Ser. Hort. Series 75.

Marsh, A. W., H. Johnson, Jr., L. J. Booher, N. McRae, K. Mayberry, P. Mobray, D. Ririe, and F. E. Robinson. 1977. *Solid Set Sprinklers for Starting Vegetable Crops*. Univ. of California Div. ANR Leaf. 2265.

Marsh, A. W., R. L. Branson, S. Davies, C. D. Gustafson, and F. K. Aljubury. 1975. *Drip Irrigation*. Univ. of California Div. ANR Leaf. 2740.

Maynard, D. H., and G. H. Hoehmuth. 1997. *Knott's Handbook for Vegetable Growers*. John Wiley & Sons, New York.

Nakayama, F. S., and D. A. Bucks. 1986. *Trickle Irrigation for Crop Production: Design, Operation, and Management*. Elsevier, Amsterdam, Netherlands.

Oebker, N. F., and J. R. Kuykendall. 1971. Trickle irrigation in horticultural crops in the desert Southwest. In: *Proc. Nat. Agric. Plast. Conf.* 11.

Pair, C. H. 1976. *Sprinkler Irrigation*. USDA, ARS Leaf. 476.

Takatori, F. H., L. F. Lippert, and J. M. Lyons. 1971. *Petroleum Mulch Studies for Row Crops in California*. Univ. of California Agric. Exp. Sta. Bull. 634.

Wolfe, D. W., and E. Rutkowski. 1987. *Use of Plastic Mulch and Row Covers for Early Season Vegetable Production*. Cornell Univ. Veg. Crops Rep. No. 355.