Management of Irrigation for Vegetables: Past, Present, and Future

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SUMMARY. Vegetables are grown throughout the U.S. on various soil types and in various climates. Irrigation is essential to supplement rainfall in all areas to minimize plant water stress. In the U.S., irrigated vegetable production accounts for about 1.9 million ha or 7.5% of the irrigated area. California, Florida, Idaho, Washington, Texas, Nebraska, Oregon, Wisconsin, and Arizona account for 80% of the U.S. production of irrigated vegetables. In the U.S., surface and subsurface (seepage) irrigation systems were used initially and are currently used on 45% of all irrigated crops with a water use efficiency of 33%. Sprinkler or overhead irrigation systems were developed in the 1940s and are currently used extensively throughout the vegetable industry. Sprinkler systems are used on 50% of the irrigated crop land and have a water use efficiency of 75%. In the late 1960s, microirrigation (drip or trickle) systems were developed and have slowly replaced many of the sprinkler and some of the seepage systems. Microirrigation is currently used on 5% of irrigated crops. This highly efficient water system (90% to 95%) is widely used on high value vegetables, particularly polyethylene-mulched tomato (*Lycopersicon esculentum*), pepper (*Capsicum annuum*), eggplant (*Solanum melongena*), strawberry (*Fragaria × ananassa*), and cucurbits. Some advantages of drip irrigation over sprinkler include reduced water use, ability to apply fertilizer with the irrigation, precise water distribution, reduced foliar diseases, and the ability to electronically schedule irrigation on large areas with relatively smaller pumps. Drip systems also can be used as subsurface drip systems placed at a depth of 60 to 90 cm. These systems are managed to control the water table, similar to that accomplished with subsurface irrigation systems, but with much greater water use efficiency. Future irrigation concerns include continued availability of water for agriculture, management of nutrients to minimize leaching, and continued development of cultural practices that maximize crop production and water use efficiency.

Vegetables are grown extensively throughout the U.S. on various soil types and in different climates. Soils vary from coarse textured sandy soil with a water holding capacity of 8% to 15% to fine textured silt and clay soils with water holding capacities of over 40%. Organic soils are used extensively along with gravel and rock soils. Climatic conditions vary from arid regions with little rainfall, such as in California, Arizona, and parts of Texas, to humid regions with substantial rainfall, including Florida, Louisiana, and Georgia (Nonnecke, 1989). In all areas where commercial vegetables are grown, irrigation is essential to supplement rainfall to minimize plant water stress. To produce the maximum yield of high

quality vegetables, an adequate supply of water is essential throughout the plant growth cycle. Water stress due to inadequate water supply or the use of saline water results in reduced plant growth and loss of produce quality. Vegetable growth is reduced by water stress, and yield response to irrigation can be over 200% (Doss et al., 1980; Locascio and Myers, 1974).

In the U.S., 25.5 million ha of crop land are irrigated. Field corn (*Zea mays*), grains, and pasture account for 13.4 million ha and irrigated vegetable production accounts for about 1.9 million ha [including 0.45 million ha potato (*Solanum tuberosum*)] or 7.5% of the irrigated area. Irrigation is es-

sential in arid California where 31% (591,000 ha) of irrigated vegetables are produced as well as in humid Florida. In the U.S., Florida is second to California in vegetable value with 7% (130,000 ha) of the irrigated vegetables. Other states with major irrigated vegetable areas are Idaho (170,000 ha including 159,000 ha potato), Washington (163,000 ha including 71,000 ha potato), Texas (112,000 ha), Nebraska (94,000 ha), Oregon (74,000 ha), Wisconsin (72,000 ha), and Arizona (60,000 ha). These nine states account for 80% of the U.S. production of irrigated vegetables (Irrigation Journal, 2001).

Water for irrigation of all crops, parks, and golf courses is obtained from ground (37%) and surface (63%) water sources and account for 81% of the consumptive water use in the U.S. and over 90% in most western states (Solley et al., 1998). Without irrigation, crop production would not be possible in many areas in the U.S. and would be uneconomical in most areas. Although the U.S. has an abundant supply of fresh water, the demand for urban and industrial uses will continue to increase and result in increased cost of water and competition for irrigation water (Golleshon et al., 2002). A serious concern of producers will be to maintain an adequate water supply at an affordable cost.

In some areas, water is limited and the amount of water available determines the cultural practices used and the amount of a crop that can be grown. Short-term droughts often result in a decrease in the availability of surface water available for agriculture. With increased pumping, salt water intrusion into wells is a concern in some areas (Myhre et al., 1986). As rural populations continue to decrease, the urban majority will need more water and this competition for water for irrigation will result in increased water costs. To continue to be profitable, commercial agriculture must continue to increase irrigation efficiency. Vegetable irrigation practices of the past, present, and future are presented.

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Units

To convert U.S. to SI,
multiply by

0.4047
1
2.5400

U.S. unit

acre(s)
cbar
inch(es)

SI unit

ha
kPa
cm

To convert SI to U.S.,
multiply by

2.4711
1
0.3937

Surface and subsurface irrigation

In the U.S. and around the world, surface and subsurface (seepage) irrigation systems were historically used and are currently used on 45% of all irrigated crops in the U.S. (Golleshon et al., 2002). These systems, often called gravity-flow systems, require an abundance of water, gently sloping fields, and the presence of an impervious soil layer at 50- to 90-cm soil depth to maintain the water in the plant root zone. Water is surface applied in lateral ditches or underground conduits. Large quantities of water must be applied to maintain a water table at 50 to 60 cm below the crop and this results in low water use efficiency (Smajstrla et al., 1999). With continued pumping of water in some areas, salt intrusion becomes a problem. With use of poorer quality water, salts accumulate on the soil surface and as the season progresses, salinity reduces plant growth (Bernstein and Francois, 1973).

Seepage systems are less expensive to install and generally are simpler to manage than other systems. However, 5% to 10% of the crop land area is needed for surface ditches needed to transport water to and from the field, and these systems have a water use efficiency of about 33% or lower. In numerous studies, crop yields of tomato (Doss et al., 1980; Pitts et al., 1988), muskmelon (*Cucumis melo*) (Bogle and Hartz, 1986), onions (*Allium cepa*) (Ellis et al., 1986), potato, and lettuce (*Lactuca sativa*) (Sammis 1980) irrigated with seepage irrigation were similar to yields with other irrigation methods. With seep irrigated tomato, water use from 47 cm (Doss et al., 1980) to 225 cm (Pitts et al., 1988) have been reported. In the latter study, 80% of the irrigation water was estimated to have been run-off and percolation downward into the groundwater.

Seepage irrigation systems provide crop production that is equal to that with other irrigation systems, at a relative lower cost (Prevatt et al., 1981), and will continue to be widely used except in areas where water shortages exist and water is expensive. With careful application of water and recycling of tail waters, use efficiencies can be increased (Smajstrla et al., 1984).

Sprinkler irrigation

In the 1940s, sprinkler or overhead irrigation systems were developed and are currently used extensively throughout the vegetable industry. Sprinkler systems include solid-set systems, center pivot systems, lateral moving systems, and portable and traveling gun systems. Sprinkler irrigation is used on 50% of the irrigated crop land in the U.S. (Irrigation Journal, 2001). Water is conveyed to the field by conduits and applied through overhead nozzles to the crop. A high degree of water application uniformity can be obtained by overlapping the water pattern. These systems are more costly to purchase and operate, and are more complex to manage than seepage systems. However, they provide better water use efficiency (about 75%), and control water applications throughout the field (Smajstrla et al., 1999). Water is typically applied on a 5- to 7-d schedule to bring the soil to field capacity in the plant root zone with 38 to 50 cm of water applied in a typical season for tomato (Locascio et al., 1982). In contrast to surface and subsurface systems, sprinkler systems can be used where the water supply is limited and on fields with variable topography that cannot be easily leveled to accommodate seep irrigation (Stanley and Maynard, 1990). In addition to being used for irrigation, sprinkler systems are often used to cool the crop, apply fertilizer and pesticide, and for frost control (Kidder and Davis, 1955).

Microirrigation

In the late 1960s, microirrigation (drip or trickle) systems were developed (Hall, 1971) and have slowly replaced many of the sprinkler and some of the seepage systems formerly used for vegetables. Microirrigation is currently used on 5% of irrigated crops, principally on high value crops in areas where water availability is limited (Irrigation Journal, 2001). Water is applied through outlets (emitters) in low pressure hoses placed at close proximity to the crop in small amounts on a daily basis. Drip irrigation is widely used on polyethylene-mulched vegetables, particularly tomato (Locascio and Myers, 1974), pepper (Hartz et al., 1993), and strawberry (Myers and Locascio, 1972), and on unmulched and mulched cucurbits (Hochmuth et al., 1993). Drip irrigation requires

much more management than other irrigation systems but it provides more options for precise control of water, nutrient, and pesticide applications. The major benefit of drip irrigation is the high water use efficiency (90% to 95%). Water use with drip irrigation is about one-third to one-half that with sprinkler irrigation (Locascio and Myers, 1974). For efficient use of drip irrigation, water and nutrient applications must be carefully managed.

Irrigation can be scheduled by replacing a portion of the water evaporated from a U.S. Weather Service Class A evaporation pan (pan) (Phene et al., 1973; Smajstrla et al., 2000) as a measure of evapotranspiration (ET). An excess of drip irrigation reduces yield of tomato (Locascio et al., 1989). Polyethylene-mulched tomato yields with drip irrigation at 2.0 pan were lower than with 1.0 pan (Locascio et al., 1981). In a spring crop on a coarse textured soil, yields were higher with 0.5 pan than 1.0 pan (Locascio et al., 1989) with a maximum yield produced above 0.5 pan and at about 0.75 pan (Locascio and Smajstrla, 1989). On a fine textured soil, tomato yields were similar with 0.5 and 1.0 pan water quantities (Locascio et al., 1989; Olson and Rhoads, 1992) with water use of 20 to 30 cm per crop. On both soils, yields were similar with one and three irrigation applications per day. Pitts and Clark (1991) found that tomato water requirements varied from 0.2 pan in early season to 0.8 pan during fruit development. Water scheduling by pan often overestimates early crop water needs. Less water is applied with tensiometer scheduling of water at 10 to 15 kPa on a coarse textured soil. Water use on tomato was 30 cm per crop with water scheduled to replace 0.75 pan and 17 cm used where irrigation was scheduled with magnetic switching tensiometers to apply water to maintain soil at 10 kPa (Locascio and Smajstrla, 1996; Smajstrla and Locascio, 1996). On finer textured soils, water is applied to maintain the soil at 20 to 50 kPa (Locascio et al., 1992). In addition to tensiometers, soil water sensors that can be used to determine the time of irrigation include granular matrix sensors (GMS) (Eldredge et al., 1993) and time-domain reflectometry (TDR) (Topp et al., 1984).

With drip irrigation, soluble nutrients move with the wetting front. Over-irrigation results in nutrient leaching

and reduced yields (Bar-Yosef, 1977). Yields were similar with sprinkler and drip irrigation where all nutrients were applied preplant for tomato (Doss et al., 1980; Locascio and Myers, 1974) and watermelon (*Citrullus lanatus*) (Elmstrom et al., 1981). With part of the N and K applied with the drip irrigation water, yields were higher than with sprinkler irrigation for tomato (Locascio and Myers, 1974), muskmelon (Shmueli and Goldgerg, 1971), and strawberry (Locascio and Myers, 1975). With 100% preplant applied N and K, tomato yields were lower than where 50% was applied with drip irrigation (Dangler and Locascio, 1990). On a coarse textured soil, application of all P and 40% N and K preplant with 60% N and K applied with drip irrigation as compared to all nutrients applied preplant resulted in increased tomato yields (Locascio and Smajstrla, 1989; Locascio et al., 1997). With 40% preplant N and K, yields were similar with 6 bi-weekly or 12 weekly applications in either equal nutrient applications or with a variable nutrient schedule of small amounts early and larger amounts as plant growth progresses (Locascio et al., 1997) and with daily or weekly nutrient applications (Locascio and Smajstrla 1989). The use of drip irrigation has required changes in how fertilizer is applied. With drip irrigation on a coarse textured soil, it is essential for part of the N-K to be applied with the drip system and to avoid overirrigation. With only a part of the nutrients applied at planting, nutrient leaching is reduced, nutrient use efficiency is increased and generally results in higher yields than with all nutrients applied preplant or through the drip system (Locascio et al., 1997). However, on fine textured soil, yields were higher with 100% preplant nutrients than with all or part of the nutrients drip applied (Locascio et al., 1997). Split applications of nutrients were reported on pepper (Hartz et al., 1993) and muskmelon (Bogle and Hartz, 1986) to provide maximum production.

Another use of drip is as a subsurface drip system (SDI) with tubes placed at a depth of 60 to 90 cm (below the plow zone). These systems are managed to control the water table similar to that accomplished with subsurface irrigation systems but with much greater water use efficiency as water supply ditches are eliminated. Use of this system is limited to soils that are

poorly drained where a water table can be established (Phene, 1995). The SDI systems are buried and provide efficient use of water and nutrients, but in contrast to conventional drip systems, SDI can be used for several years, thereby reducing the cost of the system. These systems are suitable for process tomato (Phene et al., 1992), potato (DeTar et al., 1996), onions, lettuce, and pepper with irrigation frequencies of two times per week (Hanson et al., 2003).

Advantages of drip irrigation over sprinkler include reduced water use, ability to apply fertilizer throughout the season, precise water distribution, reduced foliar diseases, and reduced weed growth as plant foliage and row middles remain drier than with furrow or sprinkler irrigation. In addition to the application of water and nutrients, drip systems can be used to efficiently apply some pesticides, including nematocides (Overman, 1976).

Maximum yields with drip irrigation are produced with precise management of water and nutrients. However, systems are complex and include drip tubing, filters, pumps, back-flow prevention devices, injectors, and timers that require a high degree of maintenance and management. Because smaller amounts of water are applied daily with drip irrigation than with other irrigation systems, drip irrigation can be applied with a relatively smaller pump than overhead irrigation, resulting in reduced pumping cost (Prevatt et al., 1992). However, irrigation system costs are the most with drip systems (\$1200/ha) and the least with subirrigation (\$470/ha).

Future irrigation concerns include the continued availability of adequate water for agriculture, management of nutrients to minimize leaching of nutrients into the groundwater, and continuing the development of cultural practices that maximize crop water use efficiency (Golleshon et al., 2002). Drip systems offer the opportunity to economically produce a crop where water is in short supply and very costly.

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