Chapter

Principles of Irrigation Management for Vegetables

Selda Ors, Ustun Sahin, Melek Ekinci, Metin Turan and Ertan Yildirim

Abstract

Vegetables have a very high percentage of water content. Some of the vegetables, such as cucumber, tomato, lettuce, zucchini, and celery contain over ninety-five percent of water. As a result of the high-water content in the cells, they are extremely vulnerable plants to water stress and drought conditions. Their yield and quality are affected rapidly when subjected to drought. Therefore, irrigation is essential to the production of most vegetables in order to have an adequate yield with high quality. However, over-irrigating can inhibit germination and root development, decrease the vegetable quality and post-harvest life of the crop. Determination of suitable irrigation systems and scheduling to apply proper amount of water at the correct time is crucial for achieving the optimum benefits from irrigation. This determination requires understanding of the water demand of the vegetable, soil characteristics, and climate factors. All these factors have major impact for the success and sustainability of any vegetable irrigation. This section contains fundamentals of water requirements on different vegetables and summarizes important issues related to soil, water, and vegetable growth relations together with irrigation management concept by evaluating the challenging issues on the selection of proper irrigation system, suitable irrigation timing, and other parameters to increase vegetable yield in an irrigated agriculture.

Keywords: vegetable, irrigation, water, quality, yield

1. Introduction

Water is one of the important inorganic resources for all living things to maintain their vital events. Therefore, it plays a major role when it comes to consumption of nutrition in human body directly and indirectly. According to the World Health Organization, 100 liters of water per day is needed to optimally meet an individual's basic needs [1]. However, 4 billion people in the world already live in water-scarce areas. By 2050 global demand for water will increase by 20–30% and water scarcity, exacerbated by climate change, could cost some regions up to 6% of gross domestic product [2]. Besides human use, water is also very important due to the fact that its deficiency significantly restricts plant production. Water in agriculture is central to feeding the planet, providing livelihoods, and building resilience to climate shocks and extremes.

Irrigation, which is the largest usage? of water, covers the functions related to the production of cultivated plants. One of the most important conditions for the regular development of plants is to have sufficient water in the root zone during the growing season. Irrigation is the delivery of the water, to the plant root zone where the required water amount cannot be met with any precipitation. The history of irrigation begins with the history of humanity. It is known that even before the birth of civilizations, primitive irrigation techniques were used for crop production. Many civilizations have developed in areas where water is available, and irrigation can be implemented. Today, just 20% of the world's croplands are irrigated but they produce 40% of the global harvest which means that irrigation more than doubles land productivity [3].

Most of the cultivated crops needs irrigation during their growing period. Some of the field crops such as grain, wheat, rye etc. can survive under rainfed agriculture. But when it comes to vegetables, the requirement of irrigation turns into a requirement. Vegetables comprise very high percentages of water. Some of them, such as cucumber, tomato, lettuce, zucchini, and celery contain even over ninety-five percent of water [4]. Due to high levels of water content in the cells, they are critically vulnerable plants to water stress and drought conditions. Their yield and quality are affected rapidly when subjected to drought. Therefore, irrigation is essential to the production of most vegetables for having a good yield with high quality. However, over-irrigation can inhibit germination and root development, and decrease vegetable quality and post-harvest life of the crop. This can be concluded as vegetable crops may experience water stress in two different ways: firstly, when there is insufficient amount of water (drought stress), or secondly, when there is excess amount of water (waterlogging or soil water saturation). Under these circumstances the amount of irrigation water, when to irrigate and how to irrigate are the questions that have to be considered carefully. The selection of proper irrigation management is vital to maximize vegetable quality, yield, and water use efficiency while minimizing environmental impacts. Deciding suitable/efficient type of irrigation system for vegetables is quite challenging as there are so many variables such as water amount and quality, soil type, vegetable grown, and economic limitations. Once all the parameters are optimized, the highest yield could be obtained with most favorable water amount and energy.

2. Soil–plant–water relations

Plants terminate new developments in the above ground parts by minimizing the use of water and carbohydrates in the stem and help the root develop more when they cannot get enough water from the soil, and if the situation lasts or the water in the soil is insufficient, plant activities stop completely. Nevertheless, there must be sufficient air in the soil for satisfactory root development. In the conditions where there is more water in the soil, the amount of air decreases as the spaces between the soil particles are filled with water. Therefore, it is very important to balance the amount of water and air in the root zone of the plant in order to provide the best plant growth. Thus, increasing plant production depends on knowing the relations between soil, plant, and water.

2.1 Soil properties

Knowing the physical and chemical properties of the soil is fundamental to successful irrigated agriculture. Values such as field capacity and wilting point of a soil are affected by parameters such as soil texture and structure, and organic matter content [5]. Soil moisture availability varies with the amount of water in the soil and the type of the soil. Knowing soil texture and other specific characteristics is essential for planning and using an irrigation system. Since sandy soils do not have much specific surface area, they cannot hold much water. Therefore, the field capacity value of a sandy soil can be as low as 10%. Clay particles stacked on top of each other in the form of plates have a large surface area, so the field capacity of clay soils can be over 40%. As a result, clay soil does not have to be irrigated as frequently as sandy soil. Thus, for scheduling purposes it is essential to know the texture of the soil [6]. In a soil at field capacity, a mineral soil with a high organic matter content has more water holding capacity than a mineral soil with a lower organic matter content [7].

2.2 Water quality

Irrigated agriculture depends on a sufficient supply of high-quality water [8]. Agricultural water quality is also determined based on the effect of water on plant quality, yield and soil properties [9]. Properties that determine water quality for transplant irrigation are: alkalinity, electrical conductivity (EC), sodium absorption ratio (SAR), and elemental toxicities. The direct effects of irrigation water on plant growth arise either due to the creation of high osmotic conditions from plant sap or the presence of phytotoxic compounds in the water [10].

Under the effect of high osmotic pressure, the water usage of plants decrease, which is lethal for the plants. Therefore, the total salinity content of irrigation water is extremely important [11]. Plants suffer more damage from salts in the early stages of their development compared to their ripening periods. This situation leads to either a decrease in yield or no yield at all. Negative effects of dissolved salts in water could be cessation of vegetative growth in the plant. It also appears in the form of reduced plant and seed development. In a study with broccoli plant [12], both irrigation water salinities and irrigation water amounts were effective on plant yield, while only salt levels were effective on dry matter values. There has been a significant decrease in the yield from 6 dS/m, and the increase in the amount of irrigation water has decreased the yield [12]. Not all vegetables respond to salinity in a similar way; some vegetables can give acceptable yields compared to other plants at much higher soil salinity.

pH has chemical and biological importance in water as an increase or a decrease in pH affects the toxicity of some compounds [13]. The quality of irrigation water in the root medium has a direct impact on the pH of the growing media and the nutrient availability. When the proportional amount of Na ion is high, the physical properties of the soil change negatively. Excess Na in irrigation water causes soil dispersion and structural dispersal. For this reason, the Na + content of water should be calculated using % Na SAR values.

The effects of irrigation water quality on soil and plants vary depending on the physical and chemical properties of the soil, the salt resistance of the plant grown, the climate of the region, the irrigation method applied, the irrigation interval and the amount of irrigation water [14].

Due to the depletion and insufficiency of existing water resources, there is a need to seek alternative water resources. In many countries, treated wastewater is considered as an alternative irrigation water. However, heavy metals, salts and harmful chemicals can be lethal especially in raw vegetables when not managed carefully in irrigation. To determine whether the treated wastewater is suitable for irrigation, the total concentration and electrical conductivity of the dissolved substances in the water, the sodium ion concentration, the ratio of sodium ion concentration to other cations, the concentration of boron, heavy metals, other potentially toxic substances, the total concentration of Ca^{++} and Mg^{++} ions under some conditions, total solids, organic matter load, and amount of floating matter such as oil-grease and pathogenic organisms should be examined. On the other hand, wastewater irrigation for vegetables has serious concerns since most of the vegetables are consumed raw. Moreover, in most countries using wastewater as an irrigation water for the raw eatable crops is forbidden by law.

2.3 Important soil moisture levels for irrigation

In irrigation applications, it is necessary to know the amount of moisture held in the soil at certain tensions. These reference soil moisture amounts are called soil moisture constants. Major soil moisture constants in terms of irrigation are saturation point, field capacity, and wilting point. During and immediately after irrigation, all the pore space in the soil is filled with water and the soil becomes saturated. As a result of water molecules filled the pores in the soil, there is a little air in the soil, and for most crops if the soil stays saturated the crop will be damaged due to this lack of air for the roots to breathe. If there are no drainage problems, the water in the soil will drain away under gravity following irrigation, leaving space for air in the soil's pore space [6]. In many types soil, after a rain or irrigation, the water immediately starts draining deeper into the soil. After 1 or 2 days, the water content in the soil will reach, Zaten after 1-2 day diyerek zaman vermissin. To larger areas underneath the surface, a nearly constant value for a particular depth in question. This somewhat arbitrary value of water content, expressed as a percentage, is called the field capacity [15]. Wilting point also called as the permanent wilting point, can be defined as the amount of water per unit weight or per unit bulk volume in the soil, expressed in percentage, that is held so tightly by the soil matrix that roots cannot absorb this water and a plant will wilt. Therefore, in practice, plants only benefit from moisture between field capacity and wilting point. The interval between the field capacity and the wilting point is called the usable/available water holding capacity. As it is known, the most important factor limiting plant growth in arid and semi-arid climates is the lack of available water in the root zone [16]. For this reason, irrigated agriculture is an inevitable necessity in arid and semi-arid areas.

The objective of irrigation is to allow the soil moisture to reduce to a safe limit and then to irrigate the soil to bring it back to field capacity. The interval between irrigation will thus depend on the available moisture in the soil and the rate at which the soil water is abstracted by the crop [6].

3. Measuring soil moisture

Accurately measuring soil moisture and evaluating the moisture change in the soil in the vegetable root zone are very crucial in irrigation applications. The monitoring of soil moisture is a standard way to determine when vegetable crops need to be irrigated. An effective irrigation in arid and semi-arid regions is achieved by monitoring the soil moisture and determining the soil moisture content correctly [17].

There are several methods due to the development of science and technology through the years. Gravimetric method, tensiometers, granular matrix sensors or the gypsum blocks, time domain reflectometry (TDR), frequency domain reflectometry (FDR), drill & drop soil moisture probe and neutron probe are commonly used techniques or practices.

Gravimetric method is a basic method in soil moisture measurement. It can be also used to compare different methods with one another as a standard calibration method [18]. In this approach, the moisture content of the soil is determined by drying soil samples in an oven at 105°C to a constant weight and finding the amount of water lost. The moisture content is calculated by ratio as weight of water to the weight of dry soil. Generally, samples of 50 to 100 g of soil are enough in most field tests due to the large samples requiring longer drying times [18].

In other methods, different devices ranging from inexpensive simple moisture meters to much more expensive probe systems are used to measure soil moisture. These devices provide real-time monitoring of soil moisture. In the first group, water potential in soil are measured with tensiometers and the granular matrix sensors such as gypsum block and the watermark sensors. In the second group, soil moisture content considering the time or frequency of electronic pulse traveling between or returning to electrodes and capacitance sensors are measured with water content sensors. Resistance-type moisture sensors work by measuring the resistance between electrodes inserted into the soil [17].

Tensiometer is a device that measures moisture tension inside soil. It is widely used in the practice because it is inexpensive, needs no power supply, and provides direct and continuous readings [19]. They are inserted into the soil to different depths considering the effective root zone of the plants [20]. It has water-filled generally transparent looking tube with a porous ceramic at the bottom and a vacuum gauge at the top. The readings as a suction i.e. negative pressure or a potential are in kpa (kilopascals) or centibars. Tensiometer readings are not affected by the soil temperature or the osmotic potential of the water solution in the soil and work at low water retention tensions (0–85 kPa) which represent a small part of the entire range of available moisture [21].

Granular matrix sensors or the gypsum blocks with electrodes embedded in block of porous material are used to measure a resistance that reflects. The electrodes are connected to cables that extend to the soil surface for neyi read ediyor. Resistance? by a portable resistance meter providing small voltage. If water is present in the soil, the gypsum block gets wet, thus the resistance between electrodes decreases, while on the contrary the resistance increases as soil dries. Increased resistance shows an elevated tension in the soil. Therefore, resistance readings from devices are converted to actual water contents using a calibration curve later as the granular matrix sensors indirectly measure soil water tension using electrical resistance [22]. Being an inexpensive device can be seen as an advantage but it is stated that mistakes in measurements of moisture of wet soils occur frequently [19, 23].

Capacitance sensors, TDR and FDR are the techniques that consider dielectric property of the soil to measure moisture content [24]. These electromagnetic soil moisture sensors have improved throughout the last few decades considering size, cost and precision [22]. A capacitance sensor consists of two electrodes, which provide to be immersed in the soil and measure the dielectric constant that increases. Although they are inexpensive and user friendly, the common restriction for most of the capacitance sensors is that they provide measurements considering a very small soil volume, thus they do not reflect the situation in the soil away from the sensor. Therefore, they are more suitable for small volume container-grown vegetables in greenhouses. In addition, accuracy of capacitance sensors can be affected by many soil properties such as clay and organic matter contents, salinity level, bulk density, and temperature [22].

Soil moisture content is better estimated by determining the dielectric constant based on time domain reflection principle, frequency reflection principle and standing wave principle with the advanced devices. In this context, several types of soil moisture sensors have been developed as TDR and FDR [17, 25]. TDR device works according to the principle of determining the electrical conductivity (dielectric constant) value of a material based on the propagation speed of electromagnetic waves. Although it provides rapid and repeatable measurements with no health risks, unlike neutron probe technique, it is a complex and an expensive measurement equipment. It has also some disadvantages such as reflection loss in saline soils or wet soil increases conductivity [21]. Soil moisture sensors may also require calibration, and thus calibration equations to convert readings to volumetric water content are considered [22].

In the FDR with capacitance probes, by given voltage from two electrodes, soil moisture is determined under the assumption that dielectric constant of water is much higher than soil. Capacitance is measured from variation in frequency of a reflected radio wave or resonance. When the electrodes are given voltage, which induces the frequency oscillations with an oscillator to propagate an electromagnetic signal, at a certain point resonance occurs and soil moisture content is determined through this point. The accuracy and repeatability of the FDR are high, and the FDR probes give faster response time compared to TDR probes. Moreover, FDR is relatively inexpensive and has no health risks as well. However, calibration for the results needs to be done for each soil used. To obtain correct measurements, probes need to have good contact with the soil without air gaps and the moisture measurements in saline soils are generally not reliable [19, 21].

Soil moisture profile probes or drill & drop probes provide continuous soil moisture measurements from different depths over the entire length of the probe. Salinity and temperature sensors can also be found in the probe in addition to the moisture sensors. In this practice, the time taken for an electromagnetic wave to travel along a given length of a transmission line in the soil is measured. Soil dielectric properties are changed with moisture content in the soil. This leads to different electromagnetic wave travels rates in wet and dry soils. Thus, the soil moisture content can be estimated with this approach. This device might be a good option for fast, easy but short-term measurement for monitoring of the vegetable cultivated soils.

In neutron probe method which detects soil moisture using radioactive element, fast neutrons are continuously emitted from the neutron source to the soil environment during measurement. The probe device has a source and a detector. When fast neutrons collide with hydrogen atoms, they lose energy and decelerate. With increasing soil moisture content, the density of slow neutron clouds increases. The neutron meter determines the moisture content in the soil by determining the functional relationship between the density of the slow neutron cloud and the water molecules. Although it allows fast, reliable and repeated measurements at any soil depths, the neutron instrument is expensive, and has radiation hazard risk to health, thus it cannot be widely used [17]. Neutron probes and drill & drop probes can be effectively used in soils cultivated with deep root vegetables. A major restriction of these devices might be their expense for small farms.

4. Water requirements of the vegetables

Vegetable crops require more and frequent irrigation than other plants as they contain 60–90% water, and thus irrigation in arid and semi-arid regions plays a vital role in vegetable growth. The availability of sufficient water in soil is essential for good crop formation, growth, yield and quality in vegetable production. The application of frequent but low volumes of water for vegetable crop production has been proven to result in more-yield compared to few application [26].

Crops can experience water stress in two different ways, which are the water shortage (drought) and excess water (flooding, saturation) [27]. The excess water causes waterlogging in soils, and the symptoms are similar to the water deficit impeding the oxygen supply and respiration of roots and water uptake. Drought stress occurs when atmospheric conditions cause permanent water loss through evaporation or transpiration. Under stress conditions the stomatal closure occurs with a reduction of net photosynthesis, and these responses depend on the severity and duration of stress and crop growth stage [28]. As a practical approach in controlling water stress level, the leaf photosynthetic activity can be monitored since measuring stomatal conductance or resistance of plant leaves indicate the severity of water stress. In drought stress; plant development is regressed, woody structure occurs, bloom early and growth of the leaf area, stem height and chlorophyll content reduce [29]. In addition, water plays a considerable role in the nutrition consumption of plants by dissolving nutrients in the soil. The encounter of a dry soil layer during the growing period of the vegetables will prevent the enlargement and development of the roots. However, there are many ways to manage drought stress such as mulching, use of plant growth regulators, anti-transpirants, use of water absorbent polymers (e.g. hydrogel), grafting technique, use of resistant varieties, irrigation method selection (e.g. drip irrigation), water harvesting and protected cultivation [27].

Growing areas of tomatoes have increased intensively, green peas moderately, beans and sweet corn slowly between 1997 to 2017 [28]. Corn, soybeans, beans and peas are the crops that are moderately water stress sensitive while tomatoes are within the extremely drought sensitive group. Although most crops are less sensitive to water shortage during the early stages of vegetative growth, changes of many physiological traits causing the disturbance of fertility and reduction of yield appear during the generative stage [28]. Therefore, irrigation scheduling and irrigation water requirements are determined by the water stress tolerance and water use potential of the plant varieties. Water use potential of vegetable crops depends on crop type, field soil properties, irrigation system type, climatic conditions, and crop growth stage.

5. Irrigation water amount

Irrigation is likely to increase the size and weight of an individual fruit and to prevent defects. On the other hand, too much moisture reduces soluble solids in muskmelons (cantaloupes) and capsaicin (what makes the peppers hot) in hot peppers when it occurs during fruit development. In order to determine the amount of water needed for irrigation of plants, it is necessary to know the amount of water they consume, the percentage of this amount met by precipitation (effective precipitation) and the irrigation efficiency, which includes losses in transmission and application of the irrigation. Effective precipitation is ignored for the vegetables grown under greenhouse conditions [4]. Total irrigation water requirement for a crop in the field conditions can be calculated using below equation:

$$\begin{aligned}\text{Total irrigation water requirement} = &\left(\text{Crop evapotranspiration} - \text{Effective precipitation}\right)\\ &/\ \text{Transmission and application efficiency.}\end{aligned} \tag{1}$$

Part of water delivered from resource is not fully stored in the crop root zone as it is lost through evaporation, runoff and deep percolation within the irrigated area. Therefore, an application efficiency value used for calculating total irrigation water required is the fraction of the available water stored in effective root depth to water conveyed to the field. Irrigation water requirement can be reduced by drip irrigation method as drip irrigation method applies water directly to crop root area (only some parts of the soil root zone watered) which saves a considerable amount of irrigation water [30]. In this case, the total irrigation requirement value should be corrected with a wetting percentage or plant cover percentage value which is lower than 1.

6. Irrigation scheduling

Irrigation scheduling simply means application of water to crops at the required time and in the required quantity. Irrigation scheduling is one of the most effective way to increase water productivity in fertile crop production. Marketable yields for most shallow rooted vegetables can be easily damaged by short-term moisture stress of two to three days. Deficit irrigation generally results yield loss and inadequate quality in vegetables, while excess irrigation increases susceptibility to diseases, irrigation energy cost and environmental pollution risk from the nutrient leaching [31].

Different techniques of irrigation scheduling in irrigation of vegetable crops are used. They can be classified as monitoring of soil water status, water balance approach from crop water demand and observing of plant traits. Continuously monitoring soil moisture throughout crop growing period is very crucial and also requires accurate measurement with precision-based devices [32]. Soil moisture sensors can be used to regulate the interval of irrigation and, possibly, the water quantity by continuously monitoring water content or tension of the soil [31]. Technological advances in automatic soil water sensor-based irrigation systems are aimed to save an optimum soil water range in the root zone for high-quality plant growth. These algorithms are? used in automated irrigation management and scheduling agricultural activities. Furthermore, these algorithms are developed to observe water content and ensure irrigation with automated activation when necessary [33]. Smart irrigation automation systems can be less used in open field agriculture, while they are used increasingly in greenhouse production with soil or without soil to save considerable amounts of water and nutrients that are heavily applied.

Irrigation scheduling in crop water demand method consists of supplying the crop evapotranspiration (ETc) (daily, five or ten days' averages) for each crop growing stage. Thus, this method is known as crop evapotranspiration method. The ETc value of a fully-irrigated vegetable crop can be calculated either empirically by multiplying daily reference of evapotranspiration (ETo) by crop coefficient (Kc) or experimentally (2). However empirical way is commonly preferred to save time, cost and labor.

$$\mathrm{ETc} = \mathrm{ETo} \times \mathrm{Kc} \tag{2}$$

ETo is calculated by well-known Penman-Monteith (FAO) equation using daily or daily average (of five or ten days) air temperature, relative humidity, wind speed and solar radiation data [22, 34]. Kc values are selected from the tables prepared for different growth stages of vegetable crops [34]. Irrigation scheduling programs such as CROPWAT can be used as the model-based scheduling. This program uses Penman-Monteith (FAO) method with collected soil, crop and climatic data in the region [22, 35]. The precision of ET-based scheduling method depends strongly on the accuracy of the ETo estimation value, a correct Kc value determined with site-specific calibration approach, correct determination of the soil's available water holding capacity, and measuring site-specific precipitation [35, 36].

Irrigation interval can. be calculated by the ratio of readily available water (RAW) to the crop daily net irrigation water requirement (Inet) which are calculated as:

$$\mathrm{Inet}\left(\mathrm{mm\,day}^{-1}\right) = \mathrm{ETc} - \mathrm{Effective\ precipitation}, \tag{3}$$

$$\text{Irrigation interval}\left(\text{day}\right) = \text{RAW} / \text{Inet}. \qquad (4)$$

RAW is calculated by, below equation [35].

$$\text{RAW} = \left(\theta\text{fc} - \theta\text{wp}\right) \times \text{D} \times \text{MAD} \qquad (5)$$

where RAW is the readily available water content (mm), θfc is the volumetric water content at field capacity ($m^3\ m^{-3}$), θwp is the volumetric water content at the permanent wilting point ($m^3\ m^{-3}$), D is the effective rooting zone depth or the soil layer depth considered (mm) and MAD is the fraction of the total available water that is allowed to be depleted. MAD value should be kept low in vegetable irrigations to protect plants from water stress. RAW value is also equal to the net irrigation quantity applied to the soil.

Plant-based scheduling techniques have been improved from the relationship between crop water stress and soil moisture deficit to define an optimal moisture content level for crop growth. Measuring crop water stress for irrigation scheduling has been also recommended considering the variations in plant species, tissues, and phenological stages [35, 37]. The approaches have been categorized as the measurements of tissue water potential and the measurements with plant physiology-based (sap flow, stomatal conductance, thermal sensing with infrared thermometers).

Stomatal conductance is a good indicator in determination of irrigation need in many plants sensitive to water insufficiency, thus improvement of this technique among plant-based irrigation scheduling approaches has drawn increaasing attention [37]. In recent years, the use of irrigation scheduling based on the crop water stress index (CWSI), which is calculated based on the canopy temperature measured with an infrared thermometer, has gained importance. Many researchers have reported that the CWSI value can be used for preparation of irrigation scheduling [38]. This approach argues that significant increases in canopy temperature exceeding air temperature has been a good indicative for stomatal closure and water deficit stress [37].

Furthermore, a systematic method can be applied as a practical scheduling approach. In this method, water applications are managed on a time or volume basis applying every day for the same duration or in the same quantity. Moreover, it is quite practical to base irrigation scheduling on evaporation from a Class A pan as a result of the combined effect of climatic factors. This approach requires a correction coefficient (kp) (mostly changed between 0.6–0.8) to convert potential evaporation value measured in pan to the ETo value. The Kp coefficient is also expressed as Kcp when it includes the crop coefficient. Water use from fully developed vegetation can be about 75–80% of the amount of water evaporated from the pan, in other words, Kcp = 0.75–0.80. When plants do not completely cover the soil surface, actual water consumption will be less than 75% of pan evaporation. Water use for vegetable crops can be considered as 10–15% of pan evaporation during the first 1/3 of the season, 40–50% of the pan evaporation during the mid-season, and 60–80% of the pan evaporation during the last 1/3 of the growing season [39].

7. Irrigation methods

In irrigated agriculture, when operating an area for irrigation, firstly the most suitable irrigation method under the conditions should be selected, then the system required by this method must be planned, installed and operated. In general, the irrigation method to be selected must meet some conditions such as to provide uniform water distribution, to minimize deep percolation and run-off losses, not cause soil erosion, not prevent agricultural mechanization, help leaching the salt from soil.

Due to the shallow rooting depth of most vegetables and their high response to lack of water, irrigation is frequently required in small amounts. This situation is more important in greenhouses with intensive production. Vegetable growers consider drip irrigation method as an effective way to save water and that plant needs, as well as to reduce weeds, fungi and diseases. Drip irrigation minimizes water loss from run-off and deep percolation, decreases evaporation losses. It has been determined that water savings of 50–80% are achieved when compared to conventional surface irrigation methods [27]. Drip irrigation method also provides more efficient water and fertilizer usage than the sprinkler method. It also reduces disease problems because leaves are not wetted. Drip irrigation lowers energy need because of the low pump pressures required and provides more applicable opportunity of automation. However, compared to sprinkler nozzle sizes, drip system emitters have very small openings, emitters gets clogged. Therefore, it requires water quality control and some preventive solutions such as filtration and dilute acid applications. Many researchers have declared considerable benefits of drip irrigation method over other conventional irrigation methods to improve yield and water productivity (WP) of fruits and vegetables [40]. The water application efficiency is about 80–90% in drip irrigation systems [39]. Maximizing the water productivity with decreased water loss and increased yield in drip irrigation is a practical way to manage finite water supplies. Plants use large amount of the water applied from increased water efficiency. This also minimizes leaching of agrochemicals out of the field or vegetable growing containers into the environment. In the last few decades, water productivity of vegetable crop values has been improved with the use of efficient micro irrigation techniques such as micro sprinkler and drip irrigation [41]. Jha et al. [40] determined that drip irrigation method resulted higher water productivity with more than five-folds increase in potato and cauliflower compared to the furrow method. It was also observed that drip irrigation method conserves approximately 70–80% water compared to conventional flood irrigation method.

In drip irrigation systems, to avoid possible plant stress, irrigations are usually scheduled to start when allowable percentage of usable water in the soil has been consumed. This level ranges from 30% in drought-sensitive plants to 70% in drought-resistant plants. In drip irrigation, this value is usually taken as 30% (MAD value) [39].

Irrigation volume in drip irrigation system considering soil available water depletion approach can be calculated with equation below.

$$\text{Irrigation volume}\left(\text{L}\right)=\left(\theta\text{fc}-\theta\text{wp}\right)\times\text{D}\times\text{MAD}\times\text{P}\times\text{A} \qquad (6)$$

where P is the wetting factor, A is the irrigated area (m^2), and other terms are as mentioned before. Wetting ratio are considered minimum %30 in semi-arid regions, and it is 35% and 25% in arid and humid regions, respectively [42]. Wetting factor is less than 1 because especially during irrigation of plants with wide row spacing, a dry area remains between the laterals that is not wetted. In some cases, the plant covering ratio is also considered instead of this value in order to apply water according to the plant growth rate.

Irrigation volume can be also determined using the Class A pan evaporation with following equation [43].

$$\text{Irrigation volume}\left(\text{L}\right)=\text{Ep}\times\text{Kcp}\times\text{P}\times\text{A} \qquad (7)$$

where Ep is the cumulative pan evaporation measured using a standard Class A pan at considered duration (mm), Kcp is the coefficient of crop-pan evaporation, P is the wetting factor and A is the irrigated area (m^2).

Due to (Ep x Kcp) is equal to the ETc (ETc = Ep × Kcp), bunun yerine (7) de can be also used to calculate irrigation volume from the ETc values determined using other approaches empirical (e.g. Penman-Monteith) or experimental.

Author details

Selda Ors[1], Ustun Sahin[1], Melek Ekinci[2], Metin Turan[3] and Ertan Yildirim[2*]

1 Faculty of Agriculture, Department of Agricultural Structures and Irrigation, Atatürk University, Erzurum, Turkey

2 Faculty of Agriculture, Department of Horticulture, Atatürk University, Erzurum, Turkey

3 Engineering Faculty, Department of Genetics and Bioengineering, Yeditepe University, Istanbul, Turkey

*Address all correspondence to: ertanyil@atauni.edu.tr

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