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Subsurface drip irrigation: A technology for safer irrigation of vegetable crops

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Abstract

A number of recent outbreaks of foodborne illnesses in the US have been traced to contaminated water either used in washing vegetables or in irrigating them. It is readily apparent that such foods as leafy green vegetables or crops such as melons that touch the soil surface or come in contact with irrigation water can become contaminated by pathogens in irrigation water. There is strong evidence in the literature that such crops do not become contaminated so long as the edible portions of the plant do not come in contact with irrigation water or a wetted soil surface. Thus, we undertook a modeling study utilizing the well-known software, HYDRUS-2D, to determine minimum depths of placement of irrigation tubing for subsurface irrigation that ensure that the soil surface does not become contaminated. We chose to model a cropping system commonly used for lettuce production in Arizona where the crop is nearly always irrigated using furrow irrigation. Lettuce is usually grown in Arizona in the fall and winter months when maximum crop evapotranspiration (ET) is about 4.9 mm per day. We used an application efficiency of 95% for subsurface drip irrigation on two different soil types, sandy clay loam and loam. Assuming that we would irrigate daily for two hours to apply the required 5.2 mm of water, we found water would wet the soil to a distance of 16 cm above the drip emitter in the both the clay loam and clay soils. Thus it would appear that in these soils, a drip tube placed 20 cm below the surface should avoid soil surface wetting. However, given the great spatial variability in such soil parameters as bulk density and hydraulic conductivity, we would recommend a minimum design depth of 30cm to avoid soil surface wetting.

Keywords: Subsurface drip irrigation, Simulation, Crop contamination, HYDRUS 2D

1. Introduction

Over the past ten years a number of incidences of "food poisoning" traced to fresh vegetables has caused greater attention to focus on the safety of irrigation systems and practices. In many instances, the contaminant is one or more pathogens such as *Salmonella*, *E. Coli* or enteric viruses. In some instances, this contamination has been traced to the irrigation water. While irrigation with even "treated" waste water is not allowed for food crops such as vegetable in the US, water from irrigation canals can often contain certain levels of one or more of these pathogens [1].

Most vegetable crops in the US are irrigated using surface irrigation via a furrow system. Such systems allow the water to come in direct contact with the above ground portions of the plant, particularly the plant leaves which, for leafy green vegetables such as lettuce or spinach are the edible portions of the plant. Drip irrigation, where the tubes and emitters are placed on the surface has also been shown to allow contamination of edible portions of the plant [2]. Even in those instances where subsurface drip irrigation has been attempted on such crops, the tubes and emitters have been placed close enough to the surface to allow surface wetting by capillarity [1]. Alternatively, some research has shown that when drip tubing and emitters are placed at a depth that precludes wetting of the soil surface, little or no contamination of the edible portions of the plants occur, even for leafy green vegetables [2-4].

The overall objective of this study was to determine the minimum depth at which drip irrigation tubing could be placed in two different soils common to the lettuce growing region Arizona to avoid wetting the soil surface while providing adequate water to the crop.

2. Materials and methods

In this study the program, HYDRUS 2D, is used to determine the wetting pattern from a subsurface drip emitter for sandy clay loam and loam soils. This model has been widely used for modeling subsurface drip irrigation systems and verified as an accurate predictor of soil wetting patterns under a wide range of conditions [5-6]. In Arizona, lettuce is usually grown in the fall and winter months near Yuma. We utilized a crop coefficient for lettuce developed by Oliveira [7] at Maricopa, Arizona and weather data from the Yuma AZMET station to estimate maximum ET during the growing season as 4.9 mm/day. We assumed a reasonable application efficiency for a subsurface drip irrigation system of 95%, which means that a gross application of 5.2 mm/day would be required. For vegetable crops such as lettuce the

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Table 1 Soil Properties

Soil Texture	Saturation MC %	Field Capacity MC %	Permanent Wilting Pt. %	Sat. Hydraulic Conductivity, cm/hr
Sandy Clay Loam	39	27	17	1.31
Loam	43	28	14	1.04

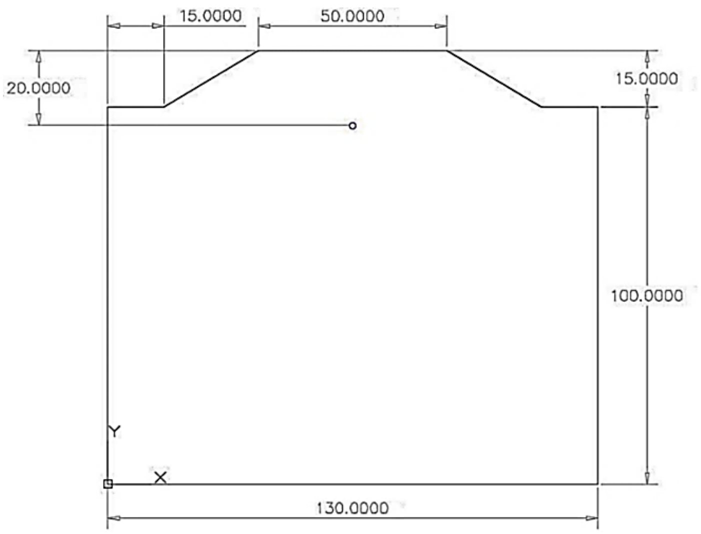

Figure 1 Solution space for drip irrigation simulation

maximum allowed soil water depletion (MAD) is generally accepted as 30%, so that the initial water content at the time of irrigation would be 70% of field capacity. Table 1 shows the soil-water relationships for the two soils.

HYDRUS 2D is a two-dimensional, finite element model developed by scientists at the US Department of Agriculture Salinity Laboratory in Riverside, CA [6]. It provides a numerical solution of the Richards equation [8] to simulate soil moisture and water flow in unsaturated soils. The HYDRUS-2D model uses the two-dimensional form of Richards' equation to describe transient water flow in isotropic unsaturated soils:

$$\frac{\partial\theta}{\partial t} = \frac{\partial}{\partial x}\left[K(h)\frac{\partial h}{\partial x}\right] + \frac{\partial}{\partial z}\left[K(h)\frac{\partial h}{\partial z} + K(h)\right] - S(h) \quad (1)$$

where θ is the soil's volumetric water content [L3 L−3], *h* denotes the soil water pressure head [L], *S(h)* is a source flux term [L3 L−3 T−1] representing the drip emitter, *t* signifies time [T], *K(h)* is the unsaturated hydraulic conductivity function [LT−1], and *x* and *z* are the horizontal and vertical spatial coordinates [L], respectively, of the simulated soil domain. Solution of this equation requires characterization of the soil hydraulic properties, as defined by the soil water retention, θ*(h)*, and the unsaturated hydraulic conductivity function, *K(h).*

To simulate the drip irrigation system, an emitter flow rate of 3.73 L/m/h was used to provide the required 5.2 mm/day with an irrigation time of one hour per day. This assumed an emitter spacing of 0.23 m along the drip tape. However, to ensure that the soil surface would not be wetted if irrigation time exceeded the one hour, we simulated irrigation with this flowrate for two hours. For our initial simulations, we located the emitter at 20 cm below the surface. Lettuce in Arizona is typically planted on raised beds with furrows between the beds as shown in Figure 1, which also illustrates the solution domain for the simulation. Thus the total depth of the solution domain is 115 cm and the width is 130 cm with the drip emitter located 20 cm below the surface of the raised bed.

Model output provided volumetric soil moisture content as a function of time and space in the solution domain described above. This "wetting pattern" was then utilized to determine appropriate depth placement of the tubing to avoid wetting the soil surface.

3. Results and discussion

Figure 2 shows the water content vs depth from the surface for Sandy Clay Loam soil after irrigation for two hours. From this figure, it can be seen that the soil is saturated to a distance above the emitter of about 6 cm and is wetted above the initial moisture content for a distance of about 16 cm above the emitter (located at 20 cm below the surface). This would not allow a sufficient safety factor to ensure that the surface would remain uncontaminated if wastewater was used for irrigation. Thus, a greater depth of placement will be required. This is similar to the findings of Song, et al. [1] who found that while drip tapes placed at 15 cm below the surface in a sandy loam soil resulted in minimal surface wetting, they recommended deeper placement to ensure the surface would not be contaminated by pathogens in the irrigation water.

Figure 3 shows the water content vs depth from the surface for the loam soil for two hours of irrigation.

The results in Figure 3 for the loam soil are very similar to those for the sandy clay loam soil with the soil saturated to a distance of about 6 cm above the emitter and wetted to above the initial moisture content for about 16cm above the emitter. Thus for both soils, an emitter depth below the surface of 20 cm would not be satisfactory. We recommend placement at a 30 cm depth for both soils if one was irrigating lettuce with water containing pathogens.

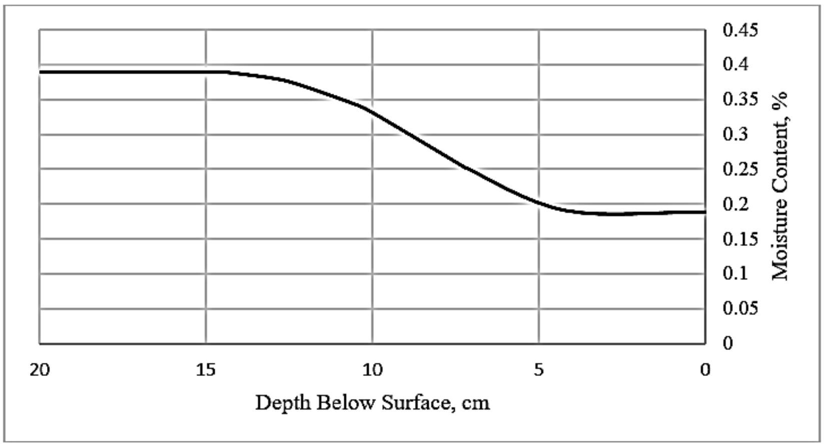

Figure 2 Moisture content below the surface after 2 hours of irrigation – Sandy Clay Loam soil

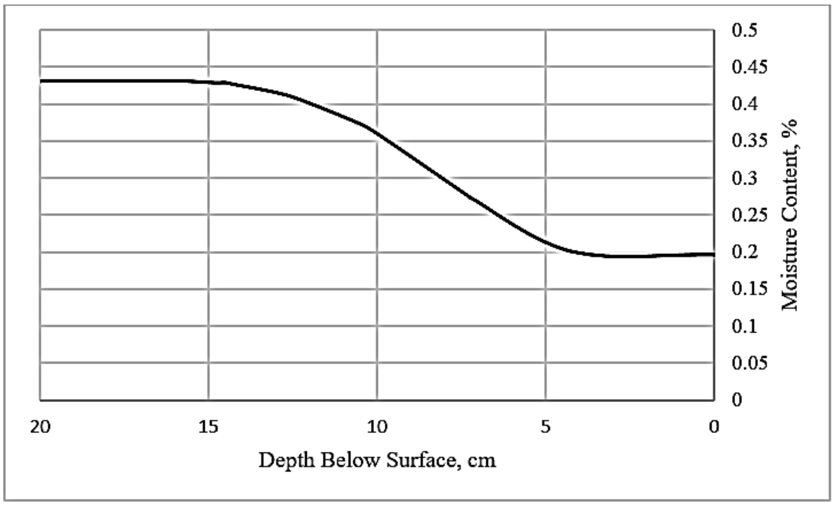

Figure 3 Moisture content below surface after 2 hours of irrigation – Loam soil

4. Summary and conclusions

Subsurface drip irrigation for a mature lettuce crop was simulated using HYDRUS 2D software to evaluate an appropriate depth of placement of drip emitters to avoid wetting the soil surface, thereby preventing potential contamination of the crop if the irrigation water contained pathogens. The simulation was performed for both a Sandy Clay Loam and a Loam soil, which are typical of the soils in the fresh produce growing region near Yuma, Arizona, USA.

Results showed that an irrigation time of 2 hours with an emitter flowrate of 3.73 L/m/h would result in the soil becoming saturated to a distance of 6 cm above the emitter for both soils. Both soils would be wetted to above the pre-irrigation moisture content for a distance of about 16 cm above the emitter.

To ensure that the soil surface would not become wetted with the irrigation water, thereby leading to potential contamination of the lettuce crop, we recommend placing the drip emitters 30 cm below the surface.

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