"El saber de mis hijos hará mi grandeza"

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USING HYDRUS-2D MODEL TO EVALUATE WATER CONTENT IN VERTICAL DIRECTION FOR LETTUCE UNDER SUBSURFACE DRIP IRRIGATION

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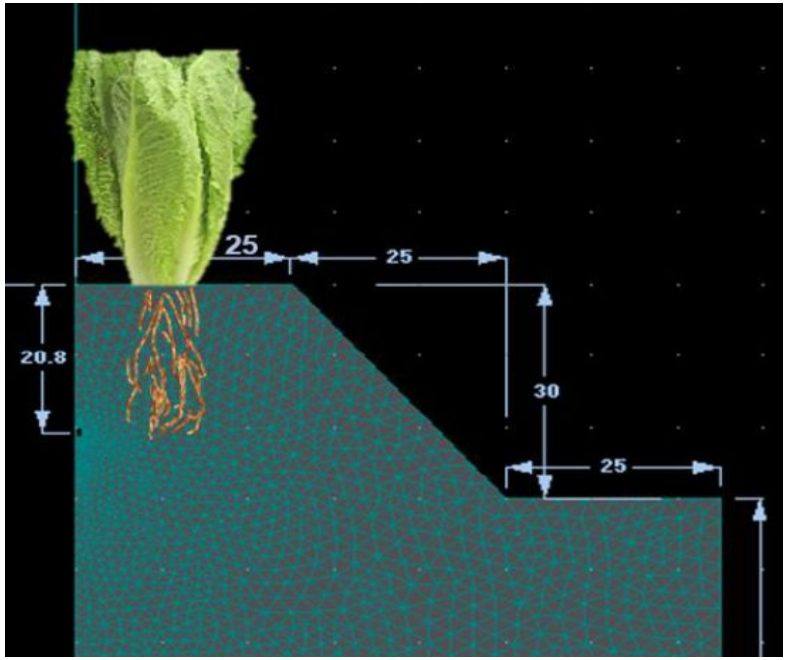
Introduction

- Produce can become contaminated by irrigation water (Beuchat, 2002).
- Water movement and soil surface wetting patterns appeared to be directly associated with crop contamination (Song, 2004).
- Subsurface drip irrigation (SDI) can be a technique for safer irrigation with contaminated water (Reyes and Slack, 2021).
- SDI involves drip application equipment installed below the soil surface (ASAE 2005).
- HYDRUS-2D is a software for modeling and simulating water, heat, and solute movement in two and three-dimensional variably saturated media (Šimůnek et al., 2008).
- HYDRUS 2D/3D simulations have been validated and calibrated with experimental data in many successful research studies (Provenzano G., 2007).

Objective



- To investigate design approaches associated with SDI to suggest design and management solutions by utilizing HYDRUS-2D model.
- Evaluation of a minimum depth at which SDI dripline could be placed in a typical Gila loam soil to leafy greens in growing Arizona.
- To determine if SDI systems with the appropriate design and management can reduce or eliminate the contamination of the edible portions of a leafy green vegetable when contaminated irrigation water is used.

Materials and Methods

Numerical Modeling with HYDRUS-2D

Richards' equation (1931)

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

Where:

θ □ soil's volumetric water content ($cm^3\ cm^{-3}$)

h □ soil water pressure head (cm)

$S(h)$ □ sink term ($cm^3\ cm^{-3}\ day^{-1}$) representing plant root water uptake

t □ time (day)

$K(h)$ □ unsaturated hydraulic conductivity function ($cm\ day^{-1}$)

x and z □ horizontal and vertical spatial coordinates (cm).

Materials and Methods

Table 1. Soil hydraulic function parameters of Gila loam soil. Killen (1988).

Soil type	θ_r (cm^3 cm^{-3})	θ_s (cm^3 cm^{-3})	α_{VG} (cm^{-1})	n	K_s (cm day^{-1})	l
Gila Loam	0.078	0.39	0.036	1.56	5.02	0.5

The unsaturated hydraulic properties were calculated using the Mualem (1976) and van Genuchten (1980) equations and represented the effective saturation, S_e by:

$$S_e = \frac{\theta - \theta_r}{\theta_s - \theta_r} = \frac{1}{(1 + |\alpha_{VG}\ h|^n)^m}$$

And the unsaturated hydraulic conductivity as:

$$K(h) = K_s S_e^l \left[1 - \left(1 - S_e^{\frac{1}{m}}\right)^m\right]^2$$

Where:

θ_r □ residual water content (cm^3 cm^{-3})
θ_s □ saturated water content (cm^3 cm^{-3})
S_e □ effective water saturation
K_s □ saturated hydraulic conductivity (cm day^{-1})
α_{VG} □ inverse of the air entry value (cm^{-1})
n □ index parameter related to the pore size distribution
$m = 1 - 1/n$
l □ pore connectivity parameter.

Materials and Methods

The sink term, *S(h)*, is the volume of water removed per unit time from a unit volume of soil due to plant water uptake. Feddes et al. (1978) defined it as:

$$S(h) = \propto (h)\ x\ S_p$$

Where:
α(h) dimensionless root water-uptake response function
Sp potential water uptake rate (day-1)

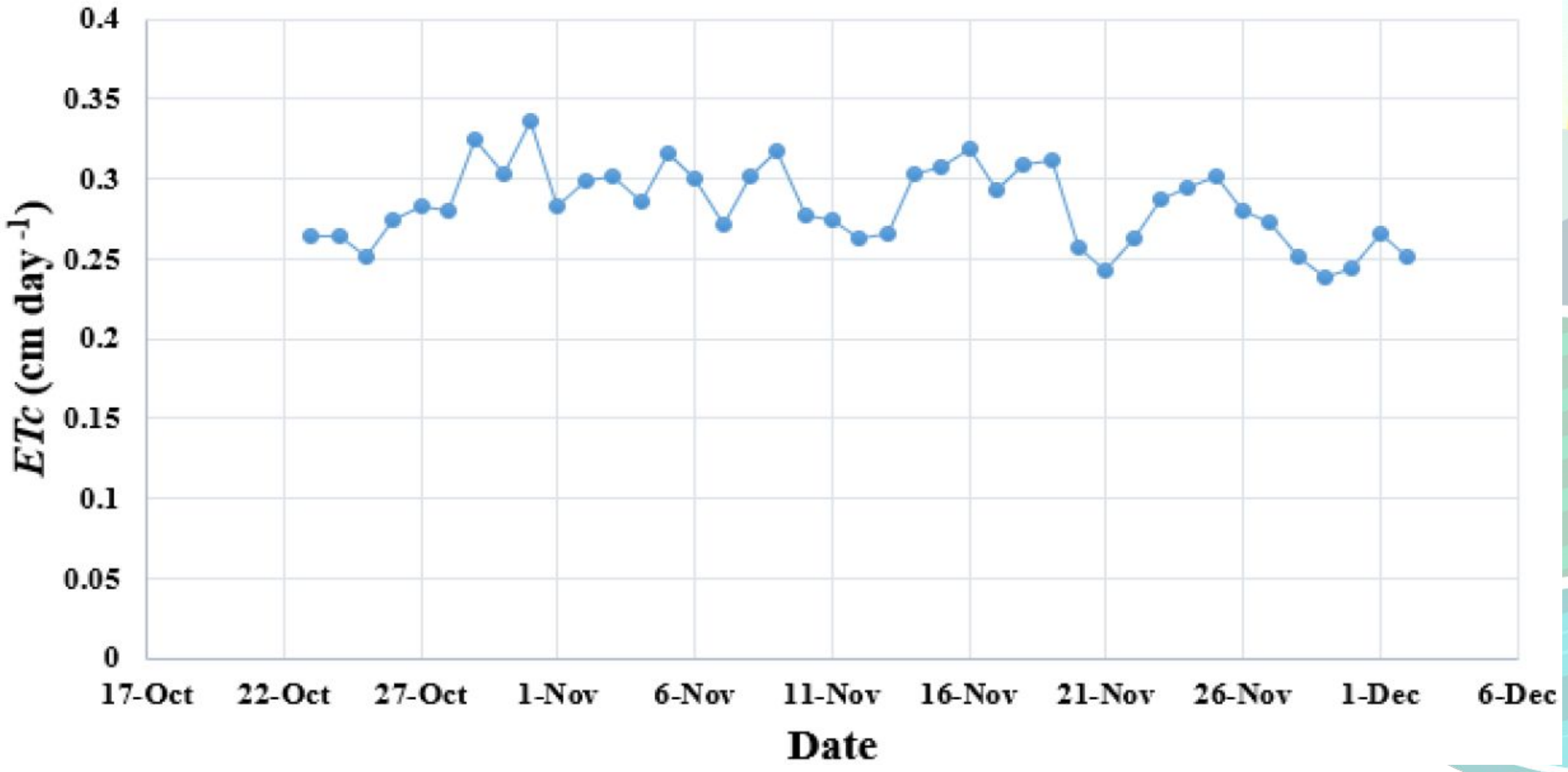
Lettuce Water Requirements

Crop evapotranspiration of lettuce *ETc* was calculated with the Penman-Monteith equation (Allen et al., 1998):

$$ET_c = K_c * ET_o$$

K_c was 0.26 at the initial growth stage, between 0.26 and 1 at the development stage, 1 at the mid-season, and 0.90 at the late-season based on Oliveira (2005).

Figure. 1 Lettuce *ETc* during the simulated period (Oct 23, 2019 − harvesting Dec 2, 2019).



Water Flux Simulations with HYDRUS-2D

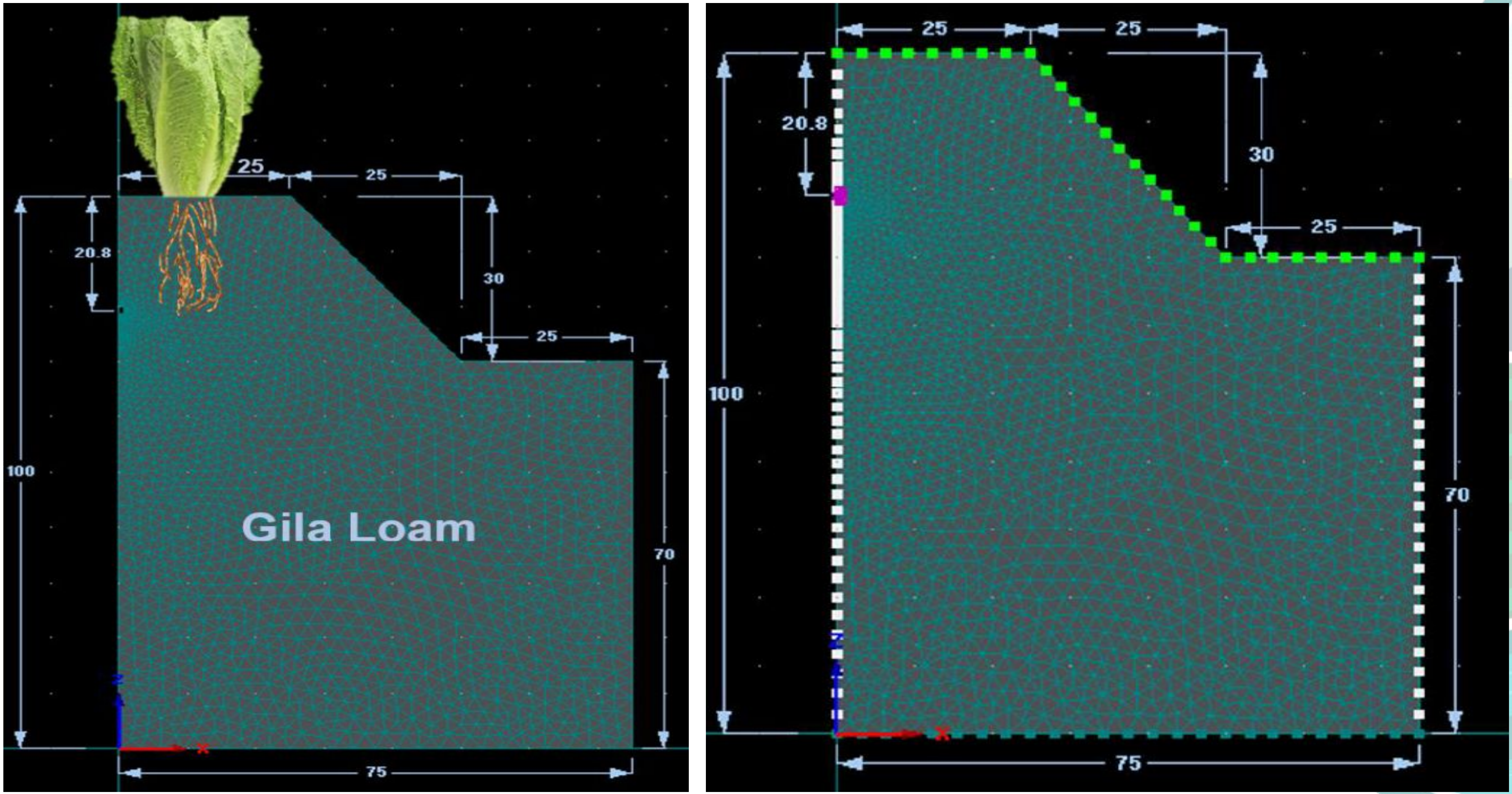


Figure 2. Space domain, finite-element mesh, and boundary conditions of SDI of the field simulations.

Water Flux Simulations with HYDRUS-2D

Table 2. Two modeling scenarios were utilized in HYDRUS 2D/3D.

Scenario	Flux water discharge (cm day^{-1})
1	Gross irrigation (0.25 – 0.35) according ET_c variations.
2	Gross irrigation of 0.51 (300 ml)

Day #	Date	ET_c (cm day^{-1})	Net Irrigation (cm day^{-1}) for scenario 1	Gross Irrigation (cm day^{-1}) for scenario 1	Net Irrigation (cm day^{-1}) for scenario 2	Gross Irrigation (cm day^{-1}) for scenario 2	Event
1	23-Oct-19	0.26	0.26	0.27	0.48	0.51	Irrig. 1
2	24-Oct-19	0.26	0.26	0.28	0.48	0.51	Irrig. 2
3	25-Oct-19	0.25	0.25	0.26	0.48	0.51	Irrig. 3
4	26-Oct-19	0.27	0.27	0.29	0.48	0.51	Irrig. 4
5	27-Oct-19	0.28	0.28	0.30	0.48	0.51	Irrig. 5
6	28-Oct-19	0.28	0.28	0.30	0.48	0.51	Irrig. 6
7	29-Oct-19	0.32	0.32	0.34	0.48	0.51	Irrig. 7
8	30-Oct-19	0.30	0.30	0.32	0.48	0.51	Irrig. 8
9	31-Oct-19	0.34	0.34	0.35	0.48	0.51	Irrig. 9
10	1-Nov-19	0.28	0.28	0.30	0.48	0.51	Irrig. 10
11	2-Nov-19	0.30	0.30	0.00	0.00	0.00	No irrigation
12	3-Nov-19	0.29	0.29	0.30	0.48	0.51	Irrig. 11
13	4-Nov-19	0.32	0.32	0.00	0.00	0.00	No irrigation
14	5-Nov-19	0.30	0.30	0.32	0.48	0.51	Irrig. 12
15	6-Nov-19	0.27	0.27	0.00	0.00	0.00	No irrigation
16	7-Nov-19	0.30	0.30	0.32	0.48	0.51	Irrig. 13
17	8-Nov-19	0.32	0.32	0.00	0.00	0.00	No irrigation
18	9-Nov-19	0.28	0.28	0.29	0.48	0.51	Irrig. 14
19	10-Nov-19	0.27	0.27	0.00	0.00	0.00	No irrigation
20	11-Nov-19	0.26	0.26	0.28	0.48	0.51	Irrig. 15
21	12-Nov-19	0.27	0.27	0.00	0.00	0.00	No irrigation
22	13-Nov-19	0.30	0.30	0.32	0.48	0.51	Irrig. 16
23	14-Nov-19	0.31	0.31	0.00	0.00	0.00	No irrigation
24	15-Nov-19	0.32	0.32	0.34	0.48	0.51	Irrig. 17
25	16-Nov-19	0.29	0.29	0.00	0.00	0.00	No irrigation
26	17-Nov-19	0.31	0.31	0.33	0.48	0.51	Irrig. 18
27	18-Nov-19	0.31	0.31	0.00	0.00	0.00	No irrigation
28	19-Nov-19	0.31	0.31	0.00	0.00	0.00	No irrigation
29	20-Nov-19	0.24	0.24	0.25	0.48	0.51	Irrig. 1 CW
30	21-Nov-19	0.26	0.26	0.28	0.48	0.51	Irrig. 2 CW
31	22-Nov-19	0.29	0.29	0.30	0.48	0.51	Irrig. 3 CW
32	23-Nov-19	0.29	0.29	0.31	0.48	0.51	Irrig. 4 CW
33	24-Nov-19	0.30	0.30	0.32	0.48	0.51	Irrig. 5 CW
34	25-Nov-19	0.28	0.28	0.30	0.48	0.51	Irrig. 6 CW
35	26-Nov-19	0.27	0.27	0.29	0.48	0.51	Irrig. 7 CW
36	27-Nov-19	0.25	0.25	0.26	0.48	0.51	Irrig. 8 CW
37	28-Nov-19	0.24	0.24	0.25	0.48	0.51	Irrig. 9 CW
38	29-Nov-19	0.24	0.24	0.26	0.48	0.51	Irrig. 10 CW
39	30-Nov-19	0.27	0.27	0.28	0.48	0.51	Irrig. 11 CW
40	1-Dec-19	0.25	0.25	0.26	0.48	0.51	Irrig. 12 CW
41	2-Dec-19	0.25	0.00	0.00	0.00	0.00	Harvesting

Results and Discussion

HYDRUS-2D Irrigation Modeling Results

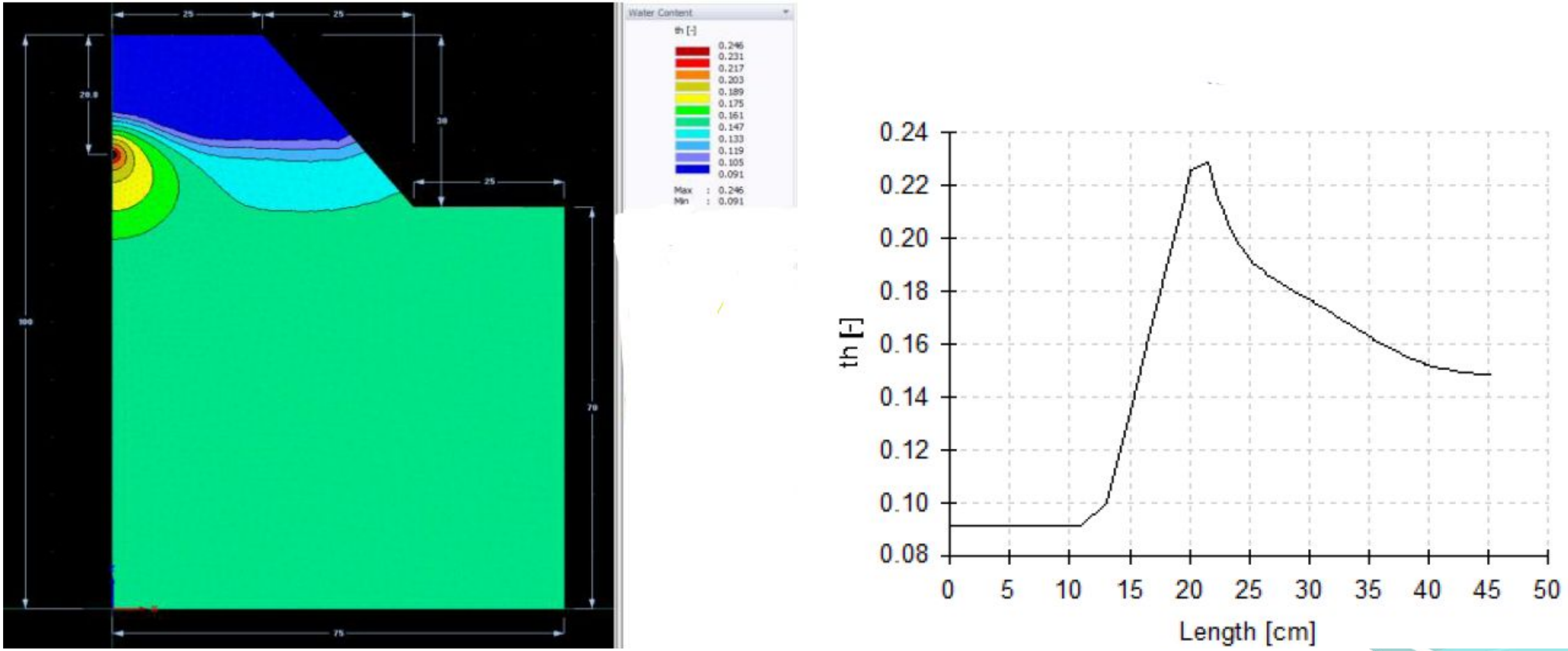


Figure 3. HYDRUS-2D simulation results of the 1st day of SDI irrigation with contaminated water (Nov. 20, 2019).

Results and

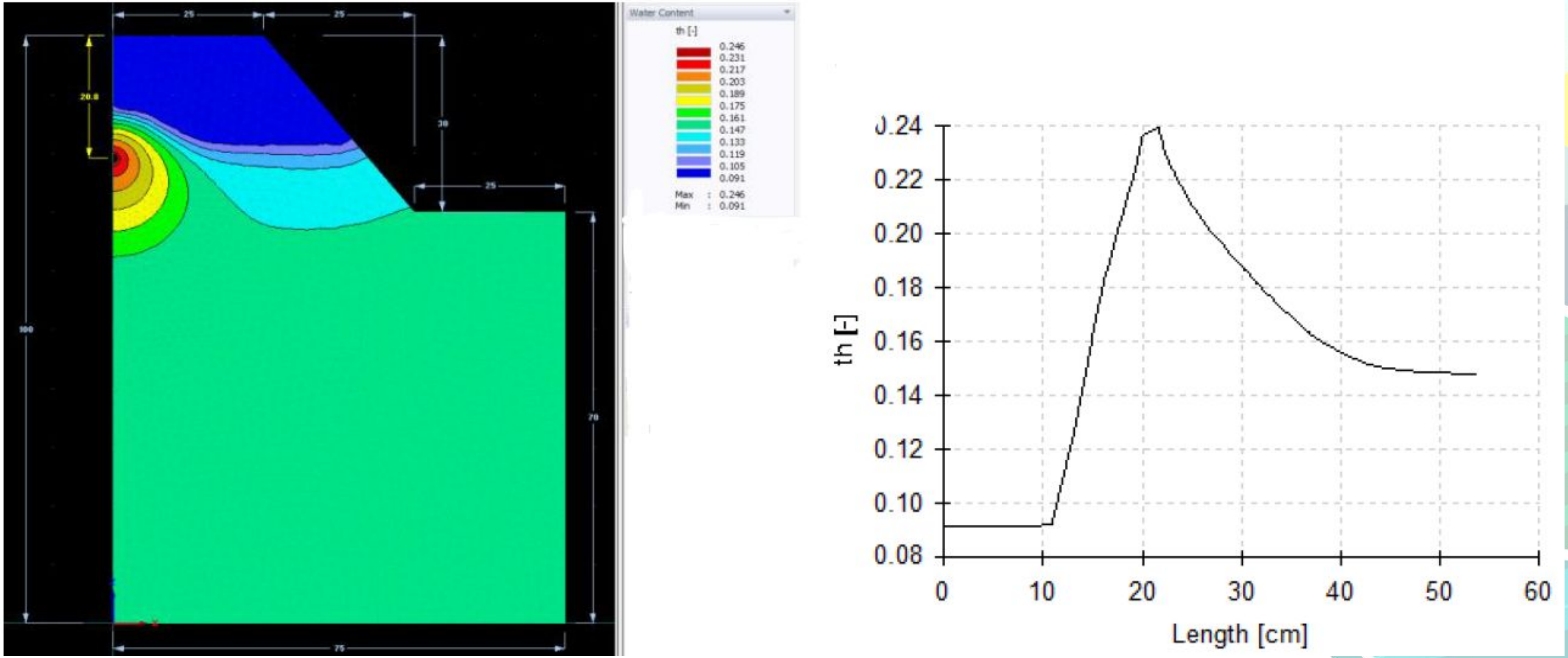


Figure 4. HYDRUS-2D simulation results of the last day of SDI irrigation with contaminated water (Dec. 1st, 2019).

Results and Discussion

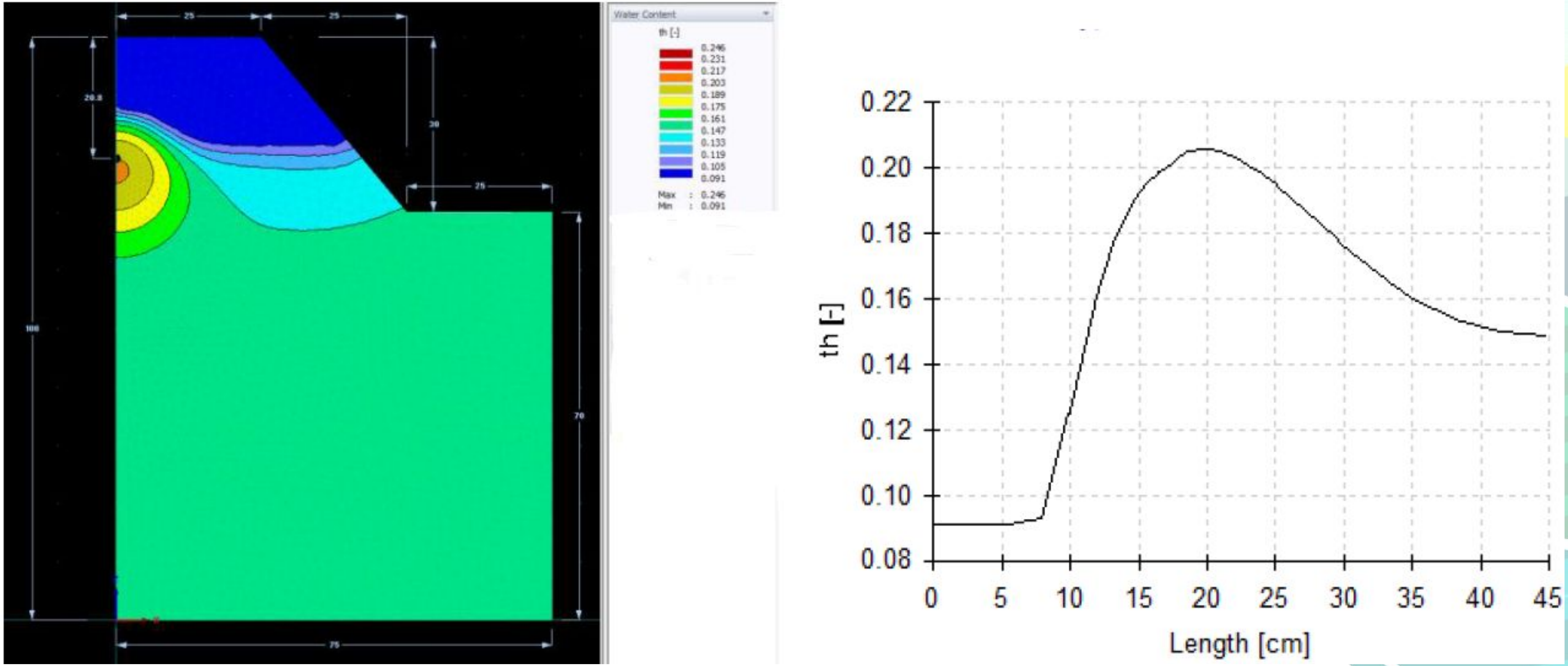
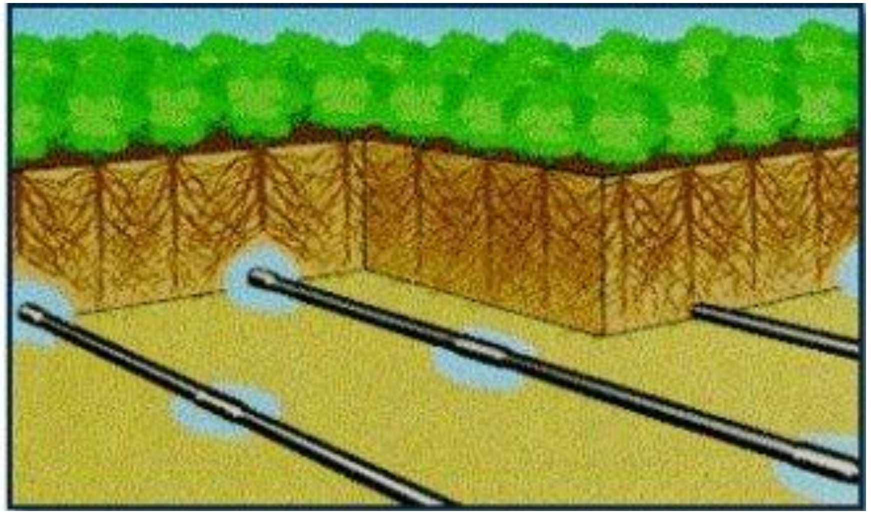


Figure 5. HYDRUS-2D simulation results of the soil moisture on the harvesting day (Dec. 2, 2019).

Results and Discussion



- Surface soil remained dry, no direct contact of contaminated water and plants.

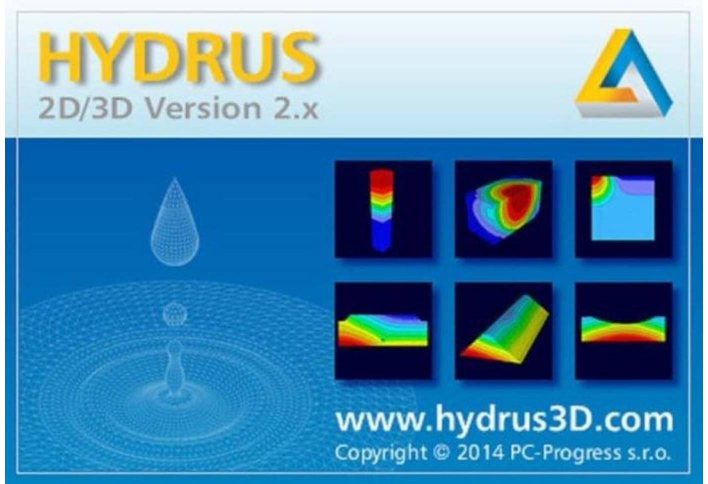
- Soil is saturated around the emitter, and the soil is wetted for a distance of about 10 cm above the emitter

- A placement at a 20 cm depth is recommended for Gila loam soil in AZ.

- This irrigation management approach does provide enough water throughout the simulated growing cycle that resulted in dry soil surfaces, no water deficit, and, therefore, no water stress.

Conclusions

- Numerical simulation is a fast and inexpensive approach for studying and optimizing design and management practices.
- The methodology presented herein can readily be applied to develop appropriate SDI designs and managements for a wide range of crops to satisfy daily crop needs, minimize water loss, and avoid soil surface wetting at harvesting time.
- These practices may guarantee dry surfaces and can be particularly useful to prevent health risks when wastewater or otherwise contaminated water is used for irrigation in arid and semiarid regions.
- Results obtained in this study suggest that SDI may provide a great alternative to other irrigation techniques when resources and the infrastructure may limit the use of extensively treated wastewater effluents.



THANK YOU!

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