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Study on Subsurface Irrigation Using Ceramic Pitcher on Tomato Cultivation in Greenhouse

-Effect of Water Pressure inside Ceramic Pitcher on Soil Moisture and Tomato Growth-

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Abstract: We investigated the impact of enforcing different water pressure values (10, 0, -30 and -50 cmH_2O) in the buried ceramic pitcher at 20cm depth below the soil surface on soil moisture movement and tomato growth in the greenhouse for subsurface irrigation. By decreasing the water pressure, the soil volumetric moisture content and tomato yield decreased, water use efficiency (WUE) increased. The volumetric moisture content decreased with time in the later stage because ceramic pitcher’s hydraulic conductivity became lower. Numerical simulation using the HYDRUS-2D code agreed well with the experimental results.

Key words: Ceramic pitcher, HYDRUS-2D, Subsurface irrigation, Tomato, Water pressure

1. Introduction

Water is becoming scarce in arid and drought prone areas. Scarce water limits economic development of these regions. Ceramic pitcher irrigation, one of the traditional subsurface irrigation methods, is used with water-filled unglazed baked ceramic pitchers, which are buried to their necks in the soil. Ceramic pitcher irrigation is very attractive for the following reasons: inexpensive, water-saving, easy to operate, and suitable for uneven terrain (Mondal *et al.*, 1987). In this study, the ceramic pitcher was buried entirely in a tomato field to evaluate the performance as an underground water emitter for subsurface irrigation. The main objectives of this study are 1) to investigate the effect of different water supply pressures on the changes in soil volumetric moisture, yield, and water use efficiency (WUE) for tomato cultivation, and 2) to develop a cultivation system in which soil moisture content can be automatically controlled using the ceramic pitcher subsurface irrigation system.

2. Materials and Methods

2.1 Properties of soil and ceramic pitcher

This work was conducted in a greenhouse at the field research station of the Tokyo University of Agriculture and Technology in Fuchu, Tokyo, Japan. The soil collected at the station was classified as volcanic ash soil, Andisol. The saturated hydraulic conductivity is 6.0 cm d^{-1}. **Figure 1** showed a schematic diagram of the ceramic pitcher used in this study. The length, the outer radius, and the inner radius of the pitcher are, respectively, 15 cm, 4 cm, and 3 cm. The saturated hydraulic conductivity is 0.012 cm d^{-1}.

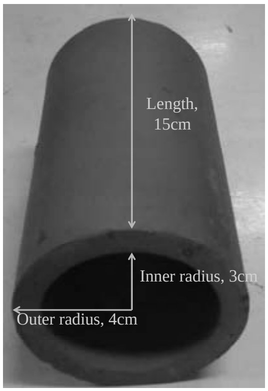

Fig.1. Diagram of the ceramic pitcher.

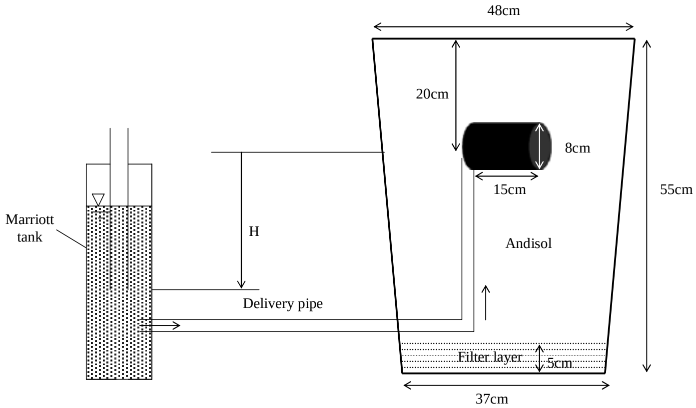

Fig.2. Schematic diagram of the experiment’s apparatus.

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2.2 Experimental setup

Four experimental treatments were designed with different water pressures (10, 0, -30 and -50 cmH_2O). The apparatus used for the experiment layout was presented schematically in **Figure 2**. A conical bucket used in this study had a 5 cm-thick sand filter layer in the bottom. A mixture of Andisol and compost were uniformly added and compacted to achieve a uniform dry bulk density of 0.70 g cm^{-3}, and a uniform volumetric moisture content of 0.40 cm^3 cm^{-3}.

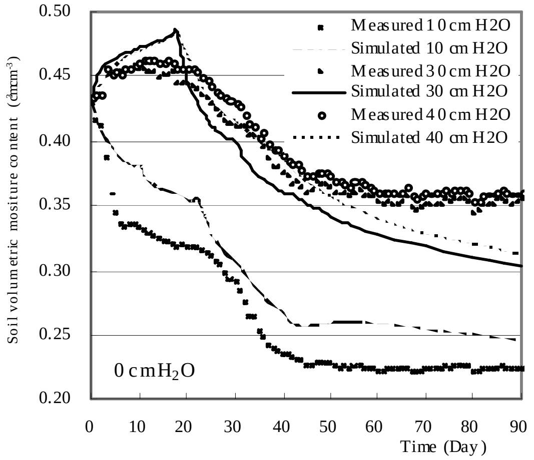
A ceramic pitcher was buried at 20 cm below the soil surface. ECH_2O soil moisture sensors (DECAGON Devices, Inc., USA) were also installed at 10, 30, and 40 cm depth to monitor the variation in the volumetric soil moisture content. Two tomato plants (*Takai momotaro T93*) were transplanted into the pot on May 11th, 2007. A constant water pressure was applied to the pitcher during the tomato growing season. After tomato fruits were harvested, the water supply was stopped before the termination of the experiment on August 10th, 2007.

2.3 Numerical simulation

The HYDRUS-2D (Simunek *et al.*, 1999) code simulates variably saturated water flow in porous media by solving the mixed form of the Richard equitation using a Galerkin finite-element method. We used HYDRUS-2D to simulate the infiltration process around the buried ceramic pitcher. The suitability of the model was assessed on the basis of the comparison between simulation results and experimental observations of soil volumetric moisture contents.

3. Results and Discussion

Data were not accurately collected for the water pressure of 10 cmH_2O. We therefore only show the results of 0, -30, -50 cmH_2O water supply pressures in the remainder of the paper.



3.1 Soil volumetric moisture content

Figure 3 presented variations of the volumetric soil moisture content at different water pressures during the tomato growth period (90 days). The water pressure decreased, the volumetric soil moisture content became less at a given depth. In all the cases, changes in the volumetric soil moisture contents could be divided into three phases. During the first phase (0～20

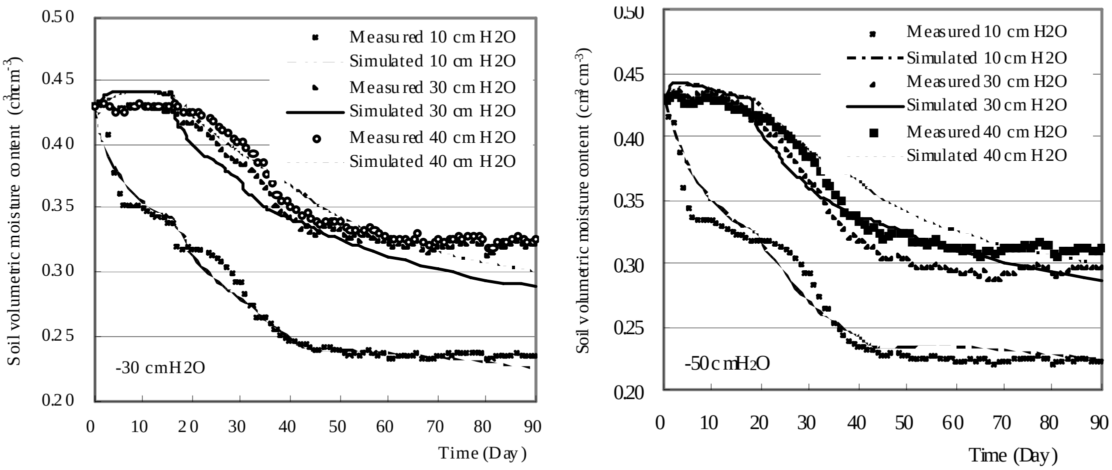


Fig. 3. Variation of measured and simulated soil moisture content for 10cm, 30cm and 40cm soil depth.

days), changes were around the pitcher (depth of 30 and 40 cm) for all three cases, while the volumetric moisture contents relatively small decrease dramatically at the depth of 10 cm for all three cases. In the next phase (20～45 days), the volumetric content decreased significantly, probably because root water uptakes by tomato and root extension were greater during this phase. At the same time, the volumetric soil moisture content decreased because the pitcher was covered by roots that take water directly from the pitcher. And then, in the final phase (45～90 days), the volumetric soil moisture contents were in general invariant and were almost at their steady states.

Figure 3 compared simulated and measured values of the soil volumetric moisture content for 10, 30, and 40 cm below the soil surface, respectively. To account for direct water uptake from the pitcher by roots covering the pitcher, in numerical simulation we modified the boundary condition during the second and third phases by decreasing the water pressure from 0, -30, and -50 cmH_2O, to -500, -700, and -800 cmH_2O, respectively. In general, the simulated values were in good agreement with the observations.

3.2 Tomato yield

Table 1 showed the tomato yield at all investigated water pressures. The 0 cmH_2O water pressure case had the best yield. The main reason for increasing the tomato yield was soil moisture content. The 0 cmH_2O water pressure case depleted more water, resulted in higher tomato yield. The relationship between the water supply pressure and the tomato yield revealed that the smaller pressure decreased the soil moisture content, and then decreased consequently the tomato yield.

3.3 Water use efficiency

Table 1 also showed the water use efficiency (WUE), which was obtained from dividing the total fresh tomato yield by the total amount of water supplied. It is useful to identify the best irrigation scheduling strategies. -50 cmH_2O water pressure gave the highest WUE. Improving irrigation method and increasing WUE in arid and semiarid region is important for water resource protection. It can be said that although the tomato yield of water pressure of -50 cmH_2O was not the highest, the WUE was the best.

Table 1. Tomato yield and water use efficiency at different water pressures.

Water pressure (cmH_2O)	Tomato yield (kg pot^{-1})	WUE (kg m^{-3})
0	1.17	24.9
-30	1.06	32.1
-50	0.95	32.8

4. Conclusions

A study of water seepage from the subsurface ceramic pitcher in Andisol under different water pressures was executed in a greenhouse of Tokyo University of Agriculture and Technology, Tokyo, Japan. While the soil volumetric moisture content and tomato yield decreased, WUE increased as the water pressure decreased. The volumetric moisture content decreased with time in the later stage because ceramic pitcher’s hydraulic conductivity became lower. Numerical simulation results obtained using the HYDRUS-2D code agreed well with the experimental results. Consequently, it can be said that low pressure irrigation can save water and improve water use efficiency. The subsurface irrigation system utilizing ceramic pitcher would be a useful and practical technique for vegetable production in arid and semi-arid regions.

References

Mondal R.C., Gupta S.K., Dubey S.K. (1987): *Pitcher irrigation*. Central soil salinity research institute, Karnal-132001, India.

Simunek J., Seina M., van Genuchten M.Th.(1999) *The HYDRUS-2D software package for simulating the two dimensional movement of water, heat and multiple solutes in variable-saturated media, IGWMC-TPS 53, version 2.0,* Int. Ground Water Modeling Center, Colorado School of Mines, Golden, Colorado.

Zhang J., Nagasawa K., Suzuki S., Nishimura T., Kato M. (2007): Development of Subsurface irrigation technology by utilizing Ceramic Pitcher- Effect of Pressure on Soil Moisture Movement inside Ceramic Pitcher-. *Journal of Arid Land Studies,* **17**(3):113-122.