

Water balance regulated by a cloud-based automatic drip fertigation system in bell pepper grown soil

Abstract

Since a fertile top soil in Fukushima, Japan was contaminated with radiocesium due to the nuclear power plant accident occurred in 2011, the fertile top soil was stripped off and replaced by a less fertile sandy soil as a decontaminating process. We applied a cloud-based drip fertigation system, called ZeRo. agri, to grow bell pepper in the less fertile soil in a greenhouse. The Penman-Monteith equation was used to estimate potential evapotranspiration (ET_p), and time domain reflectometry (TDR) probes were used to measure two-dimensional soil water distribution. The amount of excess water in soil gradually became smaller as time proceeded. Although the daily apparent root water take agreed well with the daily amount of irrigated water regulated by the cloud-based system, the Penman-Monteith equation sometimes underestimated the daily ET_p . The underestimation might be resulted from the overestimation of the aerodynamic resistance in a greenhouse.

Keywords: drip irrigation, penman-monteith equation, potential evapotranspiration, water balance, greenhouse

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Abbreviations: DAT, Day After Transplant; ET, Evapotranspiration, TDR, Time Domain Reflectometry

Introduction

Due to the accident of the Fukushima Daiichi Nuclear Power Station, top soils in surrounding areas were contaminated with radiocesium. Fertile top soils were stripped off for decontamination and replaced with a less fertile sandy soil with which crop productivity may be decreased. With recent advancements in information, communication, and electronics technologies, it becomes possible for farmers to drastically reduce working time, and to improve crop quality and water use efficiency using a cloud-based decision-making system for crop production. To maintain crop productivity in such a less fertile, we used a cloud-based automatic drip fertigation system, ZeRo.agri (Routrek Networks, Inc., Kawasaki, Japan). Based on remotely-measured soil water content and environmental conditions inside and outside a greenhouse, an irrigation rate is decided by the cloud-based irrigation system for a target volumetric water content, e.g., the field capacity, to compensate crop's water demand and irrigation conducts every one or two hours in daytime.¹ evaluated soil water content as root water uptake in vegetated soil where surface irrigation was used. There has been little study on soil water balance accounting for evapotranspiration using surface irrigation. The objective of this work was to investigate water uptake of a bell pepper plant along with evapotranspiration and water balance in the rhizosphere throughout the growing period.

Case presentation

The experiment was conducted from 7 June to 14 November in 2016 using a side-opened greenhouse (5.5 m wide and 30 m long) covered with a plastic film. The greenhouse was located in Iitate Village, Fukushima Prefecture in northern Japan. Soil texture was sandy clay loam (60% for sand, 25% for silt, and 15% for clay in mass basis). Four ridges (0.8 m wide, 30 m long) were made in parallel to the greenhouse's long direction, and irrigation tubes were laid on the

soil surface of each ridge and covered with black plastic mulch. Bell pepper seedlings were transplanted on June 5 by staggering seedlings centered on the irrigation tube with 30 cm spacing between the seedlings. Drippers with a constant irrigation rate along the irrigation tube were spaced at 20 cm apart. Liquid nitrogen fertilizer was applied with irrigation water. A certain amount of water according to the intensity of solar irradiance, determined by the cloud-based ZeRo. agri system, to make soil water the field capacity was applied through the drippers from 9 a.m. to 3 p.m. with an hour interval. The dielectric permittivity of soil was measured with 3-rod-TDR probes (100mm long, 20mm spacing with 3.2mm dia. rods)² and recorded at a 10-min interval with a CR3000 and TDR100 data logging and measuring system.³ Total 12 TDR probes were horizontally installed below a dripper and a bell pepper plant in a two-dimensional array in 3 rows with 10 cm apart at 5, 10, 20 and 30 cm deep from the soil surface. Volumetric water content, θ (m^3m^{-3}), was estimated as:

$$\theta = 4.53 \times 10^{-2} + 2.31 \times 10^{-2} \varepsilon_b - 4.00 \times 10^{-4} \varepsilon_b^2 \quad (1)$$

Where ε_b is the dielectric permittivity of bulk soil, the θ from all the 12 TDR probes at a moment were arithmetically averaged as θ_a for the rhizosphere. The apparent root water uptake by plant, U (mmd^{-1}), and daily changes in average volumetric water content, $\Delta\theta_a$ (mmd^{-1}), are expressed as:

$$U = I - \Delta\theta_a \quad (2)$$

$$\Delta\theta_a = \frac{V_a (\theta_a - \theta'_a)}{\Delta t A_a} \quad (3)$$

where I is the total amount of irrigated water in a day (mmd^{-1}), V_a is the effective rhizosphere volume (300mm long \times 200mm wide \times 350mm deep = $2.1 \times 10^7 \text{ mm}^3$), θ_a and θ'_a are average volumetric water content ($\text{mm}^3 \text{ mm}^{-3}$) at 5 a.m. on day i and day $i+1$, respectively, Δt is the time interval (d) between day i and $i+1$, and A_a is the effective rhizosphere surface area (300 mm long \times 200 mm wide =

6.010⁴ mm²). Potential evapotranspiration, ET_p , was estimated with the Penman-Monteith equation³ as:

$$ET_p = \frac{\Delta}{\Delta + \gamma} \frac{R_n + G}{L} + \frac{\gamma}{\Delta + \gamma} \left(\frac{\rho_a^0 - \rho_a}{r_{va}} \right) \quad (4)$$

where Δ is the slope of the temperature vs. saturated water vapor concentration curve ($\text{kg m}^{-3}\text{K}^{-1}$), R_n is the net radiation (Wm^{-2}), G is the soil heat flux (Wm^{-2}), γ is the psychrometric constant ($\text{kg m}^{-3} \text{K}^{-1}$), L is the latent heat of vaporization (MJ kg^{-1}), ρ_a^0 is the saturated water vapor concentration at air temperature (kg m^{-3}), ρ_a is the atmospheric water vapor concentration at air temperature (kgm^{-3}), and r_{va} is the aerodynamic resistance (s m^{-1}) for water vapor transport given by the following equation³:

$$r_{va} = \frac{1}{k^2 \bar{u}} \ln \left(\frac{z-d+z_H}{z_H} \right) \ln \left(\frac{z-d+z_M}{z_M} \right) \quad (5)$$

where k is von Karman's constant ($=0.4$), \bar{u} is mean wind speed at height $z=2$ m above the ground, assumed to be 0.6 m s^{-1} [4], d is the zero-plane displacement for the surface, and z_H and z_M are surface roughness parameters for heat and momentum, respectively. In the greenhouse, air temperature, relative humidity, net radiation at $z=2$ m and soil heat flux at 5 cm below the soil surface were measured and recorded with a CR1000 data logger (Campbell Scientific Inc., Logan, UT, USA) every 10 min. Measurement was lack between DAT=34 and 85 due to mechanical failures. Values of U would be expected to be similar to those of ET_p when plants have no water stress, meaning that the proper amount of water is irrigated. In our case, ET_p was assumed to be very close to transpiration because the soil surface was covered with a plastic multi so that evaporation from the soil surface would be negligible.

Discussion

Figure 1 shows comparison of irrigated water, I , and apparent root water uptake, U , during the growing period. Apparent root water uptake agreed well with irrigated water after DAT=86. This result indicates that the ZeRo. agri system determined and controlled the proper amount of irrigated water matched well with water demand of bell pepper plants. Excess water was applied when apparent root water uptake was smaller in the early growing period approximately between DAT=1 and 15. During this period, the Zero, agri system was in an adjusting stage to determine a proper amount of water based on try and error basis. Figure 2 indicates comparison of irrigated water, I , and potential evapotranspiration, ET_p , during the growing period. The ET_p tended to underestimate throughout the growing period. The Penman-Monteith eq. might not be used on DAT<34 because the surface cover by the bell pepper plants was not enough. In addition, water vapor concentration at T_a in the Penman-Monteith eq. might result in underestimating ET_p because air temperature distribution over the plant canopy in the greenhouse might not be well established. Fernandez et al.⁵ also reported that the Penman-Monteith equation underestimated measured greenhouse evapotranspiration resulted from large r_{va} values in Eq. 4 due to low wind velocity \bar{u} in Eq. 5. Since there was a capillary barrier layer, consisting of mostly gravel, below 30cm deep, θ at 30 cm deep little changed during the growing period so that irrigated water might not infiltrate into the

deep layer. The amount of irrigated water controlled by the ZeRo. Agri system agreed well with the amount of water required by the bell pepper plants. Therefore, we concluded that irrigated water was mostly consumed by the bell pepper plants. To improve the fertigation efficiency, further research is needed for fine-tuning the Penman-Monteith equation in a greenhouse and for configuring spatial location of crops and irrigation tubes.

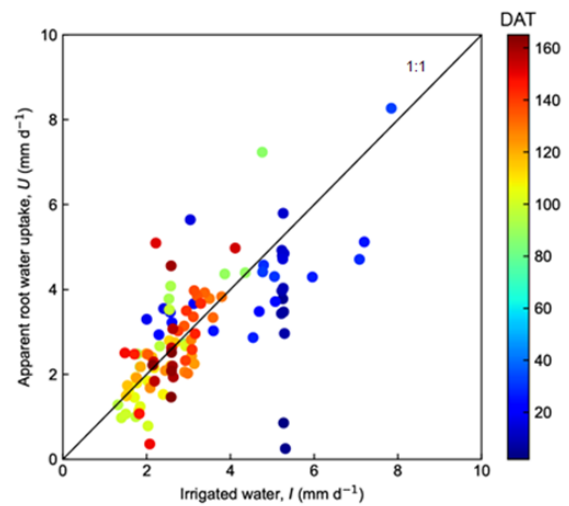


Figure 1 Comparison of amount of daily irrigated water, I , and apparent root water uptake, U .

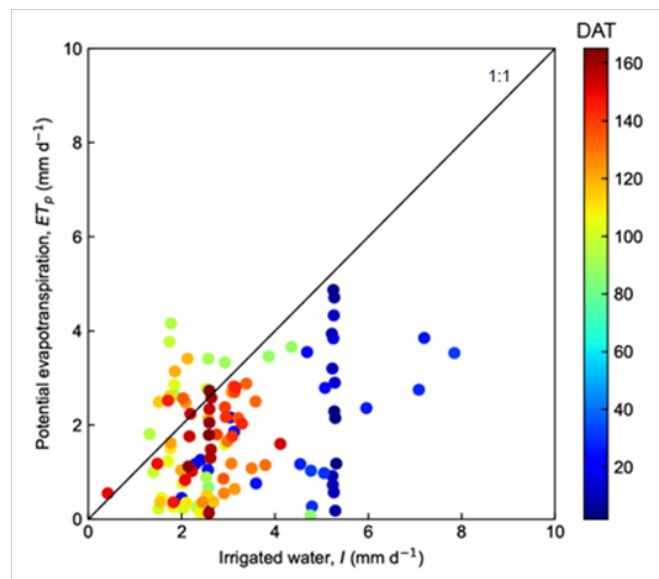


Figure 2 Comparison of amount of daily irrigated water, I , and potential evapotranspiration, ET_p .

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Conflict of interest

No financial interest or conflicts of interest exist.

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