ADAPTIVE CONTROL OF CAPILLARY WATER FLOW UNDER MODIFIED SUBSURFACE IRRIGATION BASED ON A SPAC MODEL

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ABSTRACT

The purpose of the present study is to examine the feasibility of irrigation control based on a SPAC model in the modified subsurface irrigation system. In the experiments, the soil moisture in a container was manipulated to maintain at a constant, and water demand by a tomato was measured and evaluated. The experimental setup was composed of a soil-plant system, a subsurface capillary irrigation system and a water level controller in a reservoir. A rectangular fibrous sheet situated on the planter bottom was supplied water through a string from a reservoir. The water inflow from the reservoir was determined by an electronic balance. The experiment results showed the dynamic interaction between the water inflow and the soil moisture in the soil-plant system. Good correlation has been obtained between the water inflow and the water potential of air. These results suggest the feasibility of the water potential of air as an irrigation scheduling index.

Keywords: SPAC model, Subsurface irrigation, Soil moisture, Water potential, plant water demand

INTRODUCTION

In precision irrigation, the accurate and precise application of water is required to adapt the specific requirements of individual plants and minimize adverse environmental impact. Thus the design of the system should match plant water demands resulting in reduced non-transpiration losses and optimized yield quantity and quality. Plant water demand is influenced by many parameters such as temperature, humidity, wind, cloud cover, plant growing stage, and time of year. Lysimeters have been used for the determination, but it is not easy because we need specific devices and accurate measurements of various physical parameters. Thus, easy method has been expected for precise irrigation control. A renewal theory based a model was examined for estimating the water demands for the irrigation of potatoes with use of tensiometers (Sappuntzis, 1991). The soil water and salt movement associated with a precision irrigation system ware reported (Raine et al., 2005).

Recently, potential opportunities for use of plant-based stress sensing have been considered as the basis for irrigation scheduling and control (Jones, 2004). He stressed that pressures for enhanced water use efficiency and for greater precision in irrigation systems were likely to provide a real impetus for the development of new precision irrigation scheduling systems. A simple method has been developed for precious self-irrigation that enabled the real time measurement of plant water demands (Ohaba et al., 2008). In this modified subsurface irrigation system, a micro porous ceramic pipe was used not only as a water supplier but a water flow sensor. The dynamic and modeling of soil water under subsurface drip irrigation for onions were carried out (Patel and Rajput, 2008). Further, a subsurface capillary irrigation system has been recently developed, in which a fibrous medium was improved as a water source (Ohaba et al., 2010). A similar capillary irrigation system using porous membrane with different negative pressures was developed and produced better yield and quality of hot pepper (Nalliah and Ranjan, 2010).

A new irrigation control has been tried based on a SPAC mode to adapt plant water demands (Ohaba, et al., 2011). The purpose of the present paper is to evaluate the feasibility for precious irrigation control based on the SPAC model. In the experiments, we manipulated the soil moisture at a constant, and measured the water inflow to soil. The mutual interaction between the water flux and the water potential of the air were discussed. The experimental results suggest the feasibility of the water potential of air as an irrigation scheduling index.

MATERIALS AND METHODS

Experimental setup

The experimental setup shown in Fig. 1 consists of a rectangular container with soil and a plant, a reservoir, and a water level control system. The dimensions of the container were 24cm in height, 25cm in width, and 6cm in depth. At the bottom of the container, a sheet of a rectangular fibrous (length: 25cm, width: 6cm; Toyobo, BKS0812G) was put horizontally as the water source. Water was supplied to the water source through a string from the reservoir. The soil was put into a rectangular parallelepiped fibrous touched to the water source to prevent the penetration of roots into the water source and the reservoir. Soil moisture sensors (Delta-T, SM200) were situated at the height of 4cm (point A), 7cm (point B), 10cm (point C) and 12cm (point D) cm above the container bottom. In the soil moisture control, the water head $h(t)$ was manipulated by a stepping motor system. A solar radiation sensor (Koito, IKS-37) was used. Environmental values such as solar intensity, air humidity, and air temperature were stored in a data logger (Graphtech, GL820). A commercial soil was used to cultivate tomatoes. During the experiments, the water flux was measured at real time by the rate of water entry per unit time. The experiment was conducted in a laboratory at Tokyo University of Agriculture and Technology, Faculty of Agriculture in Fuchu.

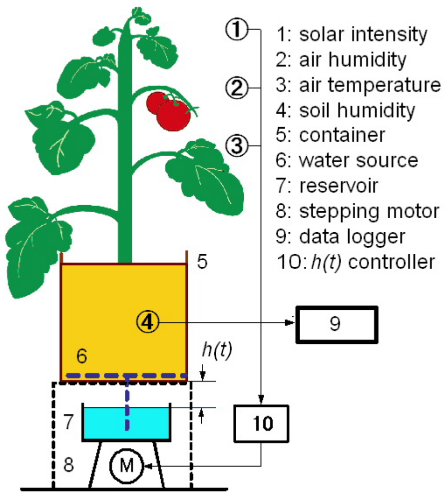

Fig. 1. Experimental setup for the adaptive irrigarion control

Theoretical background

The difference of the water potential in the soil-plant-atmosphere continuum (SPAC) model is a driving force of the water flux due to transpiration. The water flux $F(t)$ is defined by Eq. (1):

$$F(t) = (\Psi_{soil} - \Psi_{air})/(r_{soil} + r_r + r_{stem} + r_b) \qquad (1)$$

where Ψ_{soil} and Ψ_{air} are the water potentials of soil and air, r_{soil}, r_{root}, r_{stem}, and r_b are the resistances of soil, root, stem, stomata and leaf boundary layer respectively.

In Eq. (1) if we assume that Ψ_{soil} and the all resistances are constants, $F(t)$ is only affected by Ψ_{air} defined by Eq. (2):

$$\Psi_{air}(t) = - RT(t) / V_w \log_{10} [100/H_r(t)] \qquad (2)$$

where R is the gas constant, $T(t)$ is the absolute temperature of air, V_w is the volume per mole of water, $H_r(t)$ is the relative humidity of air and $\Psi_{air}(t)$ is in MPa.

When the soil moisture is a constant, the water flux is only affected byΨ_{air}. Thus we would consider the water potential of the air to a scheduling index of the subsurface irrigation. For the control of the soil moisture, we applied a proportional action of PID control, in which the soil moisture was manipulated by a linear function of the water head $h(t)$. Thus $h(t)$ is expressed by Eq. (3):

$$h(t) = K_p [r(t) - y(t)] \qquad (3)$$

where K_p is the proportional gain, $r(t)$ is the reference of the soil moisture, $[r(t) - y(t)]$ is the control error and $y(t)$ is the soil moisture.

RESULTS AND DISCUSSIONS

When water flowed into the soil, the unsaturated zone increased with time, but eventually formed a constant shape. Figure 2 shows a typical characteristic of the soil moisture response at the point D under the proportional action. The soil moisure was mainained within 41-43% from April 28th to May 3rd. However, it decreased linearly to 40% at the midnight of May 7th. The associated control action can be seen in the dynamic response in Fig. 2. After May 2nd, *h*(*t*) increased linearly acompanying small flactuations.

Figure 3 shows the daily response of the water inflow flux and its cumulation in the soil-plant system. The daily response of the water inflow flux exhibits various characteristics. The water inflow shows the maximum due to high midday transpiration, and the lowest at night. However, the daily cumulation results in almost the same, after that the cumulative water inflow flux demonstrates a linear response. Almost of this water inflow is used to evapotranspiration. The water inflow can continue as long as the water potential of the roots is more negative than that of the soil water in its immediate surrounding.

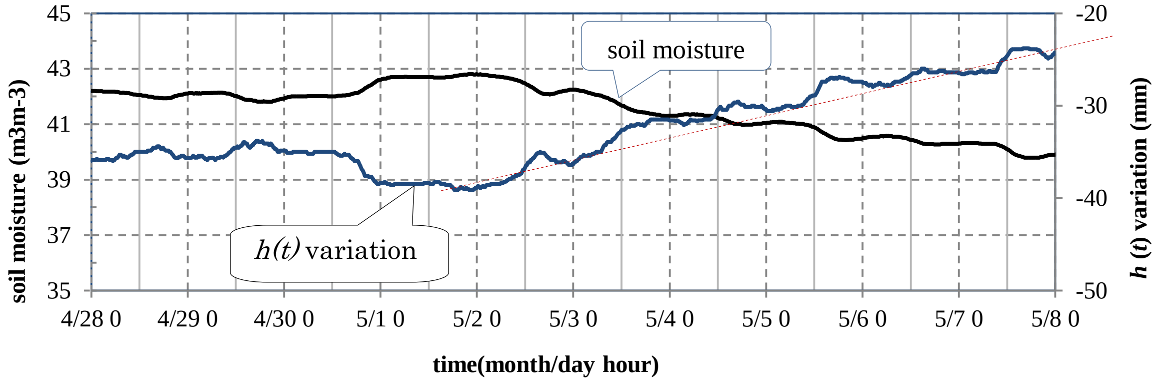

Fig. 2 Time variations of soil moisture at each point and water head controlled.

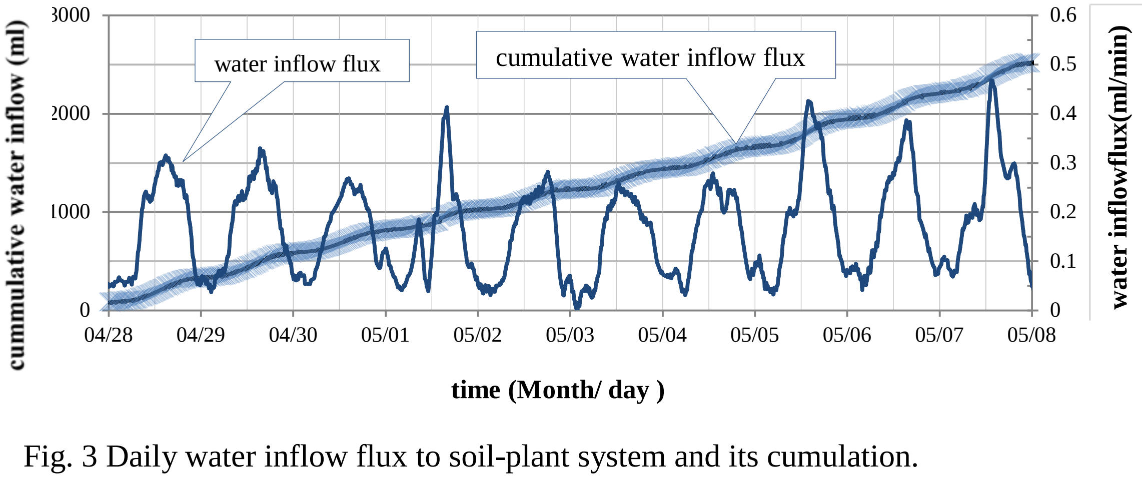

Fig. 3 Daily water inflow flux to soil-plant system and its cumulation.

Figure 4 shows the soil moisture responses at each point A-C. Before May 3rd, the soil moisture at the point A was controlled within 45-46%. After the period, it dcreased linearly accompanying daily small flactuation. In particular, the soil moisture deceased to 44% at May 7th. The flactuation of the soil moisture represents net release of water (drying process) during daytime and net storage (wetting process) at night. In the drying process, the water flux is drived by the difference of the water potential between the water sourceψ_{sou} and the plant root systemψ_{root}. In the wetting process, the water flux is also drived by the difference of the water potential between the water sourceψ_{sou} and the soilψ_{soil}. In the subsurface irrigation process,ψ_{root} is small compared toψ_{soil} in daytime, so that the cumulative water fluxe in the drying precess becomes larger than that in the wetting process. Such that the soil moisture decreases, and the soil gradually turns to dry. This phenomena are characterized by the water inflow in the modified subsurface irrigation system. Thus, the integral action is required for more precisional irrigation control.

Figure 5 shows the comparision of the cumulation between the water potential of the air (WPA) and the water inflow flux. It is clear that the cumulation of the water inflow flux exhibites a similar response of that of WPA. As WPA increases from dawn, and reaches at the maximum value at night. The maximum gap between the cumulative water inflow flux was observed significantly at May 4th at the highest relative humidity of 90%. As mentioned above, in the SPAC model, steady water flux due to plant water demands is proportional to

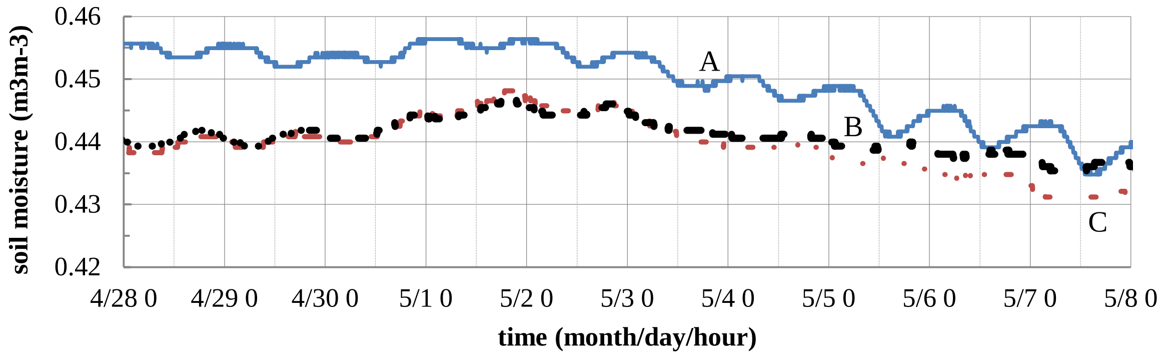

Fig. 4 Time variation of soil moisture at each point under proportional action.

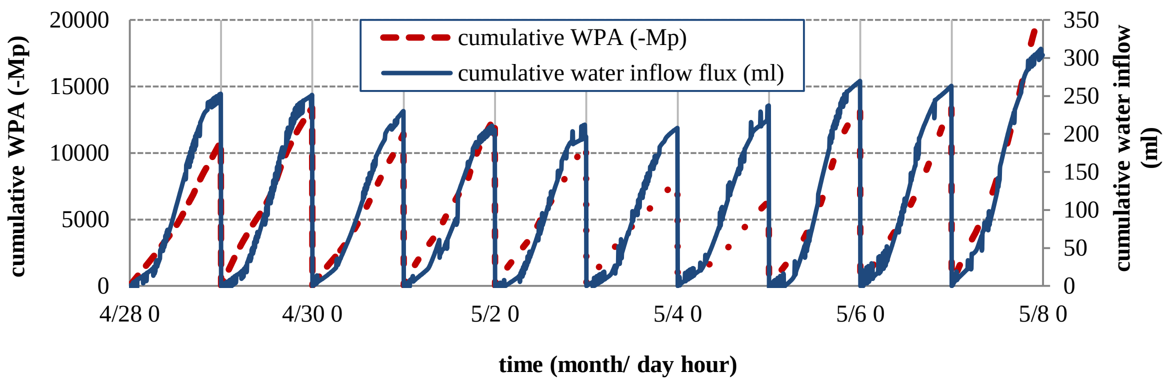

Fig. 5 Cumulative water potential of air and water inflow flux.

the water potential of air when the soil moisture maitaines at constants. Thus, we recognize this qualitative agreement in the modified subsurface irrigation system. This result suggests the feasibility to utilize the water potential of air as a control parameter to adapt water demands by plants.

CONCLUSIONS

The adaptive control of the soil moisture in the rhizosphere has been carried out under the modified subsurface capillary irrigation system. In the experiments, soil moistuure was maniplated at a constant, and the water demands by tomato was measured. The cumulative water inflow flux in the drying precess was larger than that in the wetting process. Thus, the soil moisture decreased gradually and it promoted the dryness of the soil. These processes are characterized by the water flow response in the modified subsurface capillary irrigation. For precision irrigation, the integral control action is required in the soil-plant system. Our experimental results suggest the feasibility to utilize the water potential of air as a control parameter to evaluate the water demand by plants. Future study is directed to use the SPAC model for formation of the control algorithm for precision irrigation.

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