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Estimating the actual transpiration rate with compensated levels of accumulated radiation for the efficient irrigation of soilless cultures of paprika plants

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ABSTRACT

Water management directly affects the productivity of paprika plants and is currently determined based on accumulated radiation levels. However, the amount of water used by the plants, which can be determined by their transpiration rates, does not always increase proportionally to the accumulated radiation levels, depending on the region and climate as well as crop growth stages and development. This effect is observed because the transpiration rate is also related to light intensity, which varies with the time of day and season. To develop a more efficient irrigation strategy, both factors should be analyzed based on the relationship between light intensity and transpiration rate in the short-term. In this study, a sigmoidal relationship between light intensity and transpiration rate at an interval of 10 min was observed using a consecutive transpiration monitoring system. From this relationship, a compensated equation that can calibrate the light intensity was developed. When a modified irrigation was applied using this compensated equation, less water was used compared to a conventional irrigation that supplies water proportional to accumulated radiation, especially in summer. Moreover, there were no significant differences in the transpiration rates and plant growth between plants watered with either the conventional or modified with compensated equation irrigation method. From these results, it was concluded that water was used more efficiently with the modified irrigation method without affecting plant growth. In a region with a high solar radiation in summer, such as Korea, using our equation to calculate for light intensity can prevent water waste, resulting in energy-saving and a reduction of environmental pollution in open-loop soilless cultures.

1. Introduction

Paprika is one of the most profitable horticulture crops. Given that paprika productivity is closely related to irrigation management (Sezen et al., 2006; Shongwe et al., 2010), improving the efficiency of water and nutrient use with adequate water management is critical for reducing the cost of paprika cultivation (Singandhupe et al., 2003). The approximate rate of transpiration is commonly used to estimate the amount of water that is supplied during paprika cultivation (Allen and Fisher, 1990). The transpiration rate is mostly affected by light intensity in addition to other environmental factors (Fernandez and Cuevas, 2010; Guttormsen, 1974; Shani et al., 2007). Particularly, transpiration increases with light intensity (Kim et al., 2011; Kuiper, 1961; Saez et al., 2012), crop growth stage, and development (Jolliet and Bailey, 1992; Medrano et al., 2005).

In most cases of paprika cultivation, irrigation management practices are based on the estimated transpiration amount, which is determined by the levels of accumulated radiation (De Pascale et al., 2011; Qiu et al., 2011; Shao et al., 2010; Ta et al., 2011, 2012). In general, to estimate transpiration rates, the levels of radiation accumulated daily are calculated from the sum of the photons that reach a defined area over a certain unit of time (Bryla et al., 2010; Gadissa and Chemeda, 2009; Gercek et al., 2009). In soilless culture, a conventional irrigation method supplies water proportional to accumulated radiation. However, changes in light intensity that occur during the day are ignored in these calculations. In fact, the light intensity and transpiration rate do not have a linear relationship (Ali et al., 2009; Anderson et al., 2000; Green, 1993; Rahimikhoob et al., 2012). At high light intensity condition, temperature also rises, and it alters vapor pressure deficit (VPD) condition in greenhouse (Aubinet et al., 1989; Medrano et al., 2005). It causes the stomata of plants to close during times of high light intensity,

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Fig. 1. A photograph of the experiment: 18 plants of paprika plants were grown for the experiment.

and the transpiration rate tends to decrease at these times (del Amor et al., 2010; González-Dugo et al., 2007; Kuiper, 1961). For this reason, a conventional irrigation method using a linear equation to determine the levels of accumulated radiation can cause errors in estimating the amount of water used by plants, especially under high light conditions.

The light intensity fluctuates during the day at different rates depending on the region, latitude, and season (Agele et al., 2006); thus, errors in transpiration estimation will be larger when there are large fluctuations in light intensity during the day (Sinoquet et al., 2001). For these reasons, the yield may be reduced due to drought or water excess caused by an under- or over-estimation of the transpiration rate (Ben-Gal et al., 2008; Ityel et al., 2012; Javot and Maurel, 2002; Letey et al., 2011), and nutrient solutions may be wasted due to excessive use because of an overestimation of the transpiration rate. For reduction of the overestimated irrigation amount, instantaneous transpiration with shorter interval is more favorable instead of the daily accumulated, conventionally applied for irrigation. The shorter the measurement interval is, the higher the measurement accuracy becomes by reflecting real plant response to ambient conditions.

In this study, a modified irrigation method that better estimates transpiration rates by compensating for varying light intensities and radiation accumulation was determined with a precise irrigation monitoring and control system. Water use efficiency of plant in controlled irrigation systems was subsequently compared with the compensated equation or with conventional irrigation in summer and winter.

2. Materials and methods

2.1. Growing conditions

The experiments in this study were performed in a venlo-type greenhouse located at the experimental farm of Seoul National University (Suwon, Korea, Lat. 37.3° N, long. 127.0° E). Paprika (*Capsicum annuum* L. 'Fiesta') plants were used in the experiments. Paprika seedlings with 5–6 nodes were transplanted into 0.9 m (L) × 0.15 m (W) × 0.07 m (H) rockwool slabs (Cultilène, Dae-Young GS, Chilgok, Kor.). Ten days after transplantation into the rockwool cubes, the roots began to emerge at the bottom of the cube, at which time the slabs were placed in gutters with a plant density of 3 plants m^{-2}. There were two slabs for each system. To examine the transpiration amount and water supply, three irrigation monitoring and control systems and 18 total plants were used (Fig. 1). The experiments were carried out twice in the summer and winter during February 2011–March 2012. Paprika was sown and transplanted on February 21st, 2011 and April 15th, 2011, respectively, in the summer and on July 15th, 2011 and September 2nd, 2011, respectively, in the winter. Microclimate conditions, such as daytime temperature, nighttime temperature, and relative humidity, were automatically maintained by an environmental control system within the ranges of 25–30 °C, 15–22 °C, and 50–80%, respectively, during the experimental period. The electrical conductivity (EC) and pH of the nutrient solution were between 2.6 and 3.0 dS m^{-1} and 5.5–6.5, respectively. Every irrigation event was initiated when the cumulative radiation reached 1.0×10^3 kJ/m^2. The irrigation operating time was 06:00–18:30 and 06:30–18:00 in the summer and winter, respectively. The plants were pruned to maintain two main stems, which were vertically trellised to a "V" canopy system (Jovicich et al., 2004).

2.2. Measurements

Transpiration was measured by a precise irrigation monitor and control system that was developed by Ta et al. (2012) at Seoul National University (Fig. 2). The amount of water uptake by each plant, water supply, and drainage were measured at intervals of 5 s

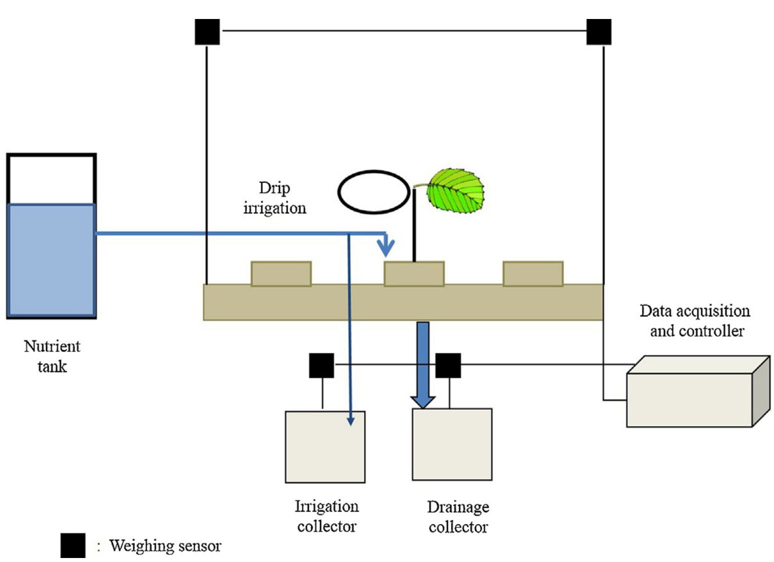

Fig. 2. A schematic diagram of an irrigation control system used in this experiment.