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Variability of Soil Water Content, Temperature, and Electrical Conductivity in Strawberry and Tomato Greenhouses in Winter

Dong-Ki Ryu[1], Myong-Jin Ryu[1], Sun-Ok Chung[1]*, Seung-Oh Hur[2], Soon-Jung Hong[2], Je-Hoon Sung[2], Hak-Hun Kim[3]

[1]Department of Biosystems Machinery Engineering, Chungnam National University, Daejeon, Korea
[2]Rural Development Administration, Gyeonggi-do, Korea
[3]Chungnam Agriculture Research & Extension Services, Chungcheongnam-do, Korea

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Abstract

Purpose: Monitoring and control of environmental condition is highly important for optimum control of the conditions, especially in greenhouses and plant factories, and the condition is not uniform within the facility. Objectives of the study were to investigate variability in soil water content and to provide information useful for better irrigation control. **Methods:** Experiments were conducted in a strawberry-growing greenhouse (greenhouse 1) and a cherry tomato-growing greenhouse (greenhouse 2) in winter. Soil water content, electrical conductivity (EC), and temperature were measured over the entire area, at different distances from an irrigation pump, and on ridge and furrow areas. **Results:** When measured over the entire greenhouse area, soil water content decreased and temperature and electrical conductivity increased over time from morning to afternoon after irrigation. Water content decreased by distance from the irrigation pump up to 70 m and increased after that, and temperature showed an inverse pattern. Soil water contents on the ridge were lower than those on the furrow, and the differences were 10.2~18.4%, indicating considerable variability. The lowest EC were observed on the furrow and highest values were observed on the ridge. Soil water contents were less and temperature levels were greater at the window side than in the center locations. **Conclusions:** Selection of number and location of soil water content sensor would be the first step for better water content monitoring and irrigation control. Results of the study would provide basic data useful for optimum sensor location and control for underground greenhouse environment.

Keywords: Greenhouse, Monitoring, Soil water content, Variability

Introduction

Protected crop production facilities have been increased in many countries due to reliable production regardless of whether condition. For example in Korea, agricultural area was decreased from 1,889,000 ha in 2000 to 1,737,000 ha in 2009, but protected production area was increased from 94,508 ha in 2007 to 97,300 ha in 2009. Major crops produced in greenhouses were high-value crops such as leaf vegetables, fruit vegetables, and flowers (KAMICO and KSAM, 2010).

In protected crop production, underground environmental factors such as soil water content, temperature, and electrical conductivity are very important for crop growth. Soil water content affects to photosynthesis of the crop, temperature regulation, and carbon dioxide gas supply. Soil temperature is closely related to absorption of nutrients and moisture, and an optimum growth condition is different by plant variety. And if proper electrical conductivity condition is not maintained, water absorption is difficult and crops cell growth is slowed (Kim, 2005; Lee at al., 2002; Yu, 2012). Chung et al. (2005) investigated spatial variability of these factors with a multiple-property soil

***Corresponding author:** Sun-Ok Chung
Tel: +82-42-821-6712; **Fax:** +82-42-823-6246
E-mail: sochung@cnu.ac.kr

sensor. Study to develop a wireless system for measuring agricultural atmospheric factors using ubiquitous sensor network (USN) was performed (Chang et al., 2011). Temperature, humidity and light intensity were selected and performance of measurement system was evaluated at greenhouse and orchard conditions. In the results, USN measuring system was effective on comprehensive measurement on the basis of time, day, and spatial sequence with reasonable costs.

In protected crop production, drip irrigation is the most widely used method to make water distribution uniform and constant (Jerzy, 1998; Nam and Kim, 2007). Gulshan and Singh (2006) reported that tomato production in a facility with fertigation equipment was improved by 59.5% compared with the case of no fertigation and by 116.2% compared with the case of open field. Irrigation scheduling could save about 50% of water (Maisiri et al., 2005). Especially drip irrigation could improve plant yield such as plant height, leaf area index, fruit weight and quality by 10~15% (Kahlon et al., 2008).

Paz et al. (1998) related root depth, hydraulic conductivity and water content of soil in 3-year research, and reported that soil water content influenced on soybean yield considerably (about 69%). Soil water solve nutrients and is absorbed through active transportation, water potential, and capillary movement (Scott, 2000), and also affects indirectly through evapotranspiration, heat capacity, surface temperature, and vegetation coverage (Dirmeyer, 1995). In study on effects of salts contained in the soil and irrigation method, drip irrigation resulted in a higher water use efficiency of 77.29 kg/m^3, compared with 19.71 kg/m^3 of furrow irrigation at salinity level of 2.0 dS/m, and improved yield by about 33% (Malash et al., 2008a and 2008b).

To maintain soil temperature, study was conducted to determine the effects of raised underground piping (Kim et al., 2010). Results showed that change of temperature on inflow and outflow was 2°C~3°C (average 2.5°C) and energy per the unit hour was 3,450 kcal/h, 57.5 kcal/h·m^2 for soil heating, respectively. Kim et al. (2011) compared growth effect of cucumber between soil heating group and non-heating group in greenhouse. In the result, height, leaf number, leaf area, fruit weight, and quantity of cucumber in heating group were 12.5, 14.6, 21.4, 22.8, 26.0% higher than non-heating group, respectively.

Conventional irrigation scheduling using timer that irrigates at a planned time based on past experience is vulnerable to unexpected weather such as heavy rainfall. Water shortage may result in prevention of leaf and stem growth, evapotranspiration and photosynthesis, and transportation of produced materials, while over supply would reduce root growth, oxygen concentration, and nutrient utilization efficiency (Ryu and Eom, 1986). Therefore continuous and accurate monitoring of soil water content is critical for precise water management and efficient utilization of soil water (Kim et al., 2003). Literature review showed that past research has mainly focused on effects of underground environmental factors on crop growth, implementation of monitoring and control of the factors, and irrigation scheduling. Investigation of variability in underground environmental factors has been limited. Objective of this research was to investigate variability in soil water content, temperature, and electrical conductivity after irrigation in greenhouses for better management of underground greenhouse environments, especially sensor-based irrigation control.

Materials and Methods

Experimental sites and used soil sensor

Experiments were conducted at two greenhouses with drip irrigation systems, strawberry-growing three-layer facility (greenhouse 1; Figure 1) and cherry tomato-growing two-layer facility (greenhouse 2; Figure 2), in December 2011 and January 2012, respectively. Dimensions of the greenhouse 1 (L, W, and H) were 100, 6.5 and 2.5 m, and the structure consisted of three layers. Both sides of greenhouse 1 could be open with window opening motors, and an irrigation system was installed. Strawberries were planted before three weeks, and harvesting started one week after the experiments. Dimensions of the cherry tomato greenhouse (L, W, and H) were 25, 7.5, and 4 m, and the structure consisted of 2 layers. Both of the side windows could be open, an irrigation system using 4-line drip pipes was installed, and the temperature could be controlled at 17°C by a heater and pipe tunnel. Cherry tomato was planted two weeks before the experiments, and tomato canopy height was about 30 cm.

Soil water content was measured using a FDR (Frequency Domain Reflectometry) sensor (WT1000N, Mirae Sensor, Seoul, Republic of Korea). The sensor provided measurements

Figure 1. Dimensions (left) and view (right) of the strawberry-growing greenhouse 1.

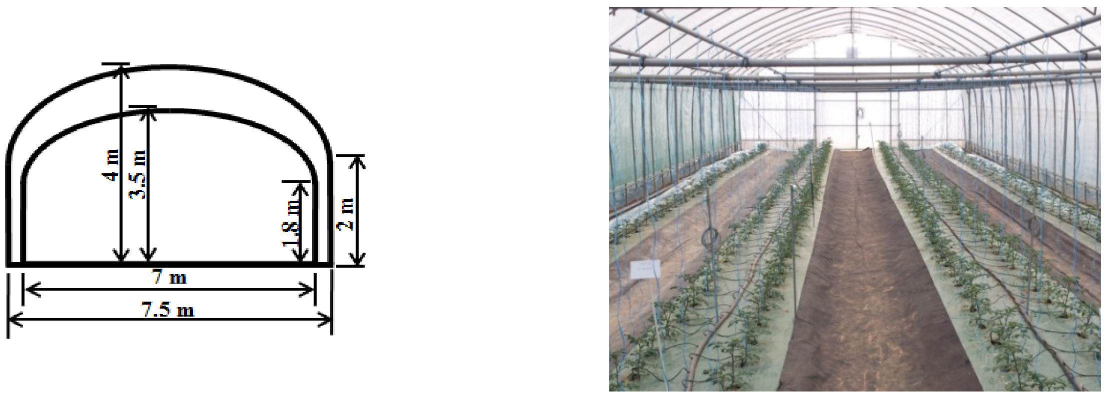

Figure 2. Dimensions (left) and view (right) of the cherry tomato-growing greenhouse 2.

Table 1. Specifications of the sensor used

Signal output	Analog	Voltage : 0 to 5 V, 1 to 5 V, 0 to 1 V,
		0 to 2.5 V (linear output)
		Current : 4 to 20 mA (linear output)
	Digital	serial TTL level 9600, N, 8, 1 (RS-232c)
Range & accuracy	Water content	0 to 99%, ±1%
	EC	0 to 6.0 dS/m, ± 0.1 dS/m
	Temperature	0 to 60°C, ±0.5°C
Sensor type		FDR (Frequency Domain Reflectometry)
Response time		≤ 2 seconds

in a range of 0~99.9% with errors about 1%, and also soil electrical conductivity and temperature values. Probe length was 11.5 cm, diameter of sensing area was 48 mm, and the response time was less than 2 seconds, as provided by the manufacturer's manual (Table 1). This sensor has widely used in Korea to digitally monitor the soil properties simultaneously and save time (e.g., Oh, 2006), and investigate spatial variability of soil water content, temperature, and electrical conductivity (e.g., Chung et al., 2005).

Experimental procedures

Strawberry was planted in six rows in greenhouse 1. Water pump was located outside of the greenhouse, and irrigation was conducted during nights from 21:00 to 5:00 at rates of 1.5~2 ton/day. Figure 3 shows measurement locations for the experiments. First, data were obtained at 9 locations across the greenhouse 6 hours and 10 hours after irrigation (Figure 3, top) to investigate overall variability over the greenhouse area. Then, measurements were taken at 10 locations in 10-m intervals along one of the irrigation pipes to investigate linear distribution of soil water content by distance from the pump (Figure 3, middle). Finally, difference in soil water content on ridge and furrow areas was measured (Figure 3, bottom).

Irrigation pump was also located out of the greenhouse 2.

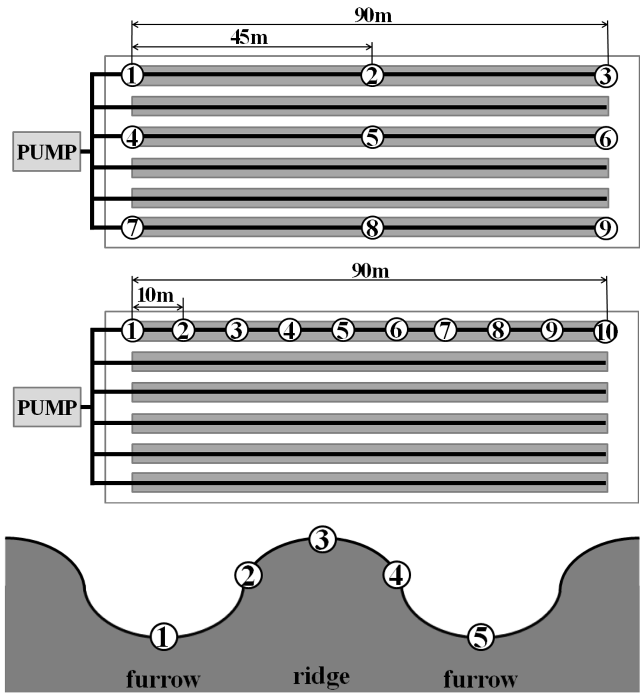

Figure 3. Diagrams explaining locations of soil water content measurements in greenhouse 1. Multiple locations across the entire area (top), along one of the irrigation pipe (middle), and on ridge and furrow areas (bottom).

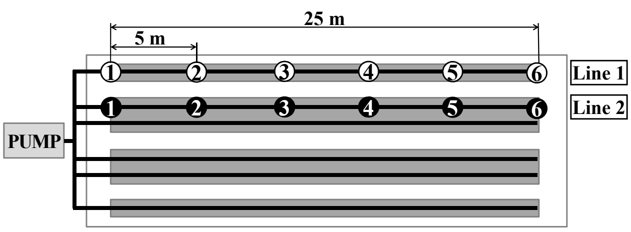

Figure 4. Diagrams explaining locations of soil water content measurements in greenhouse 2.

Fertigation was performed at 15:00 at rates of 600~800 ton/day. Soil water content was collected at 6 locations at 5-m intervals along the first and second crops rows from the side window, at 20 hours and 25 hours after the irrigation. Temperature was set to be maintained at 17°C using a heater with air tunnel around the interior perimeter of the greenhouse. Three replicate measurements were obtained and averaged at the points in each greenhouse.

Results and Discussion

Greenhouse 1 (strawberry production)

Table 2 shows results of measured soil water content, temperature, and electrical conductivity over the greenhouse area at different times (see Figure 3, top). Overall, soil water content decreased, and temperature and electrical conductivity increased over time from morning to afternoon. Difference in averaged soil water content over the time was about 3%. Water contents near the pump were greater than other locations, due to greater water pressure near the pump. Soil temperature decreased over the period by 1.4°C, and electrical conductivity values were not changed significantly over the period. Change of soil water content over time and infiltration delay of the irrigated water need to be considered for better irrigation scheduling. Spatial variability should be evaluated for selection of sensor location. For example, installation of sensor at locations providing less or greater soil water content would result in different irrigation scheduling.

Figure 5 shows measured data along the irrigation line by distance from the pump. Water content decreased by distance up to 70 m and increased after that, and temperature showed greater values at middle locations. Maximum water content was 33.1% at a 10-m distance and minimum water content was 24.5% at 60- to 70-m distance. Locations provided water contents close to the average value were

Table 2. Averaged soil water content, temperature, and electrical conductivity in greenhouse 1 at different times

Time	Location	Water content (%)			Temperature (°C)			EC (dS/m)		
11:00	1-2-3	31.3	26.3	25.0	12.4	12.7	10.0	0.6	1.0	0.8
	4-5-6	38.4	25.7	28.8	12.7	13.1	11.7	0.8	0.8	0.8
	7-8-9	38.3	25.4	23.3	11.7	11.7	10.8	0.6	0.8	1.0
15:00	1-2-3	30.0	21.4	25.4	13.4	14.2	12.5	0.8	1.0	1.1
	4-5-6	27.2	26.3	26.6	13.8	14.8	13.5	1.0	1.2	1.0
	7-8-9	29.6	26.1	24.4	12.5	13.4	11.4	0.7	1.0	1.0

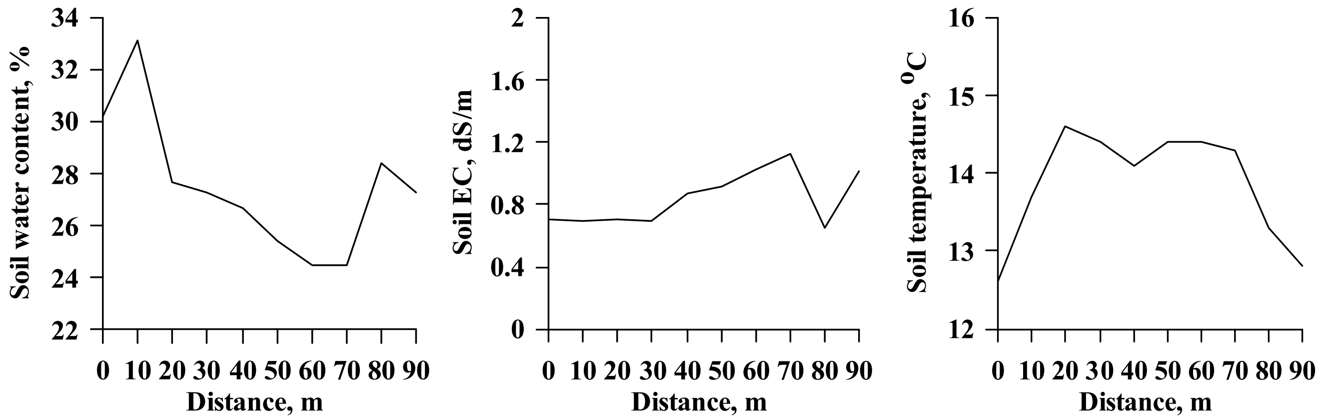

Figure 5. Variation of water content, electrical conductivity, and temperature by distance from the irrigation pump in greenhouse 1.

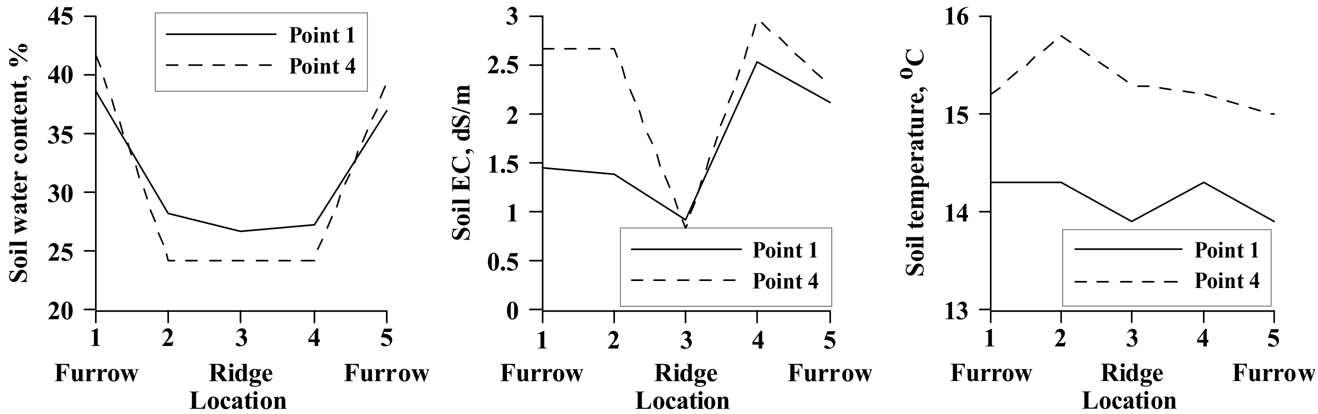

Figure 6. Variation of water content, electrical conductivity, and temperature on the ridge and furrow areas in greenhouse 1.

20, 30, and 90 m. EC showed relatively uniform distribution over the length, and average, maximum, and minimum values were 0.84, 1.13, and 0.65 dS/m, respectively. These results indicated that selection of sensor location would greatly affect irrigation scenario and performance because there was a difference of about 8% along the irrigation line.

Figure 6 shows variation in the measured data between the ridge and the furrow areas (point numbers correspond to those in Figure 3, top). Soil water contents on the ridge were lower than those on the furrow, and the differences were 10.2~18.4%, indicating considerable variability. The lowest EC were observed on the furrow, possibly due to absorption of nutrients by crop roots at those depths, and highest values were observed on the ridge. Temperature showed relatively uniform over the data collection locations. Sensor measurements should be done considering the variability and area of interest.

Greenhouse 2 (cherry tomato production)

Figure 7 shows variation of soil water content (top), temperature (middle), and electrical conductivity (bottom) by distance along the irrigation line from the pump at 20 hours (left) and 25 hours (right) after the irrigation in greenhouse 2. Except that a little decrease (2%) on the first line close to the window side, soil water content were not significantly different between the lines and measurement times. Pattern of water content along the irrigation pipe was different from that of greenhouse 1, possibly due to shorter distance of the line in greenhouse 2. Soil water content was greater at the middle locations than at the starting and ending locations. Temperature did not show significant differences by location and time, but somewhat higher values on the first line due to the heating tunnel. EC pattern was similar with the water content pattern, showing no considerable variability by distance from the pump, but values on line 2 close to the center of the greenhouse was greater than those

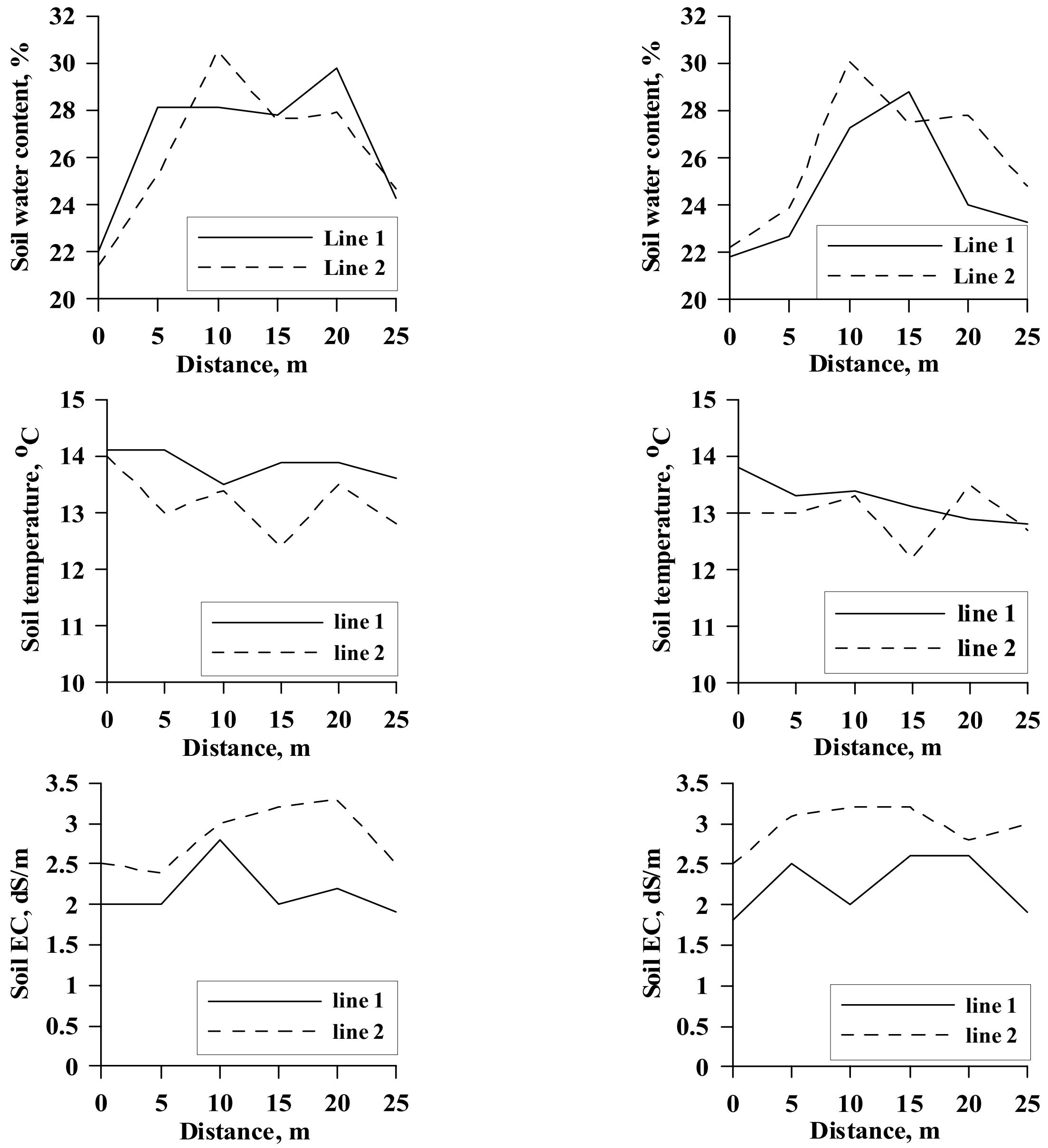

Figure 7. Variation of soil water content (top), temperature (middle), and electrical conductivity (bottom) by distance along the irrigation line from the pump at 20 hours (left) and 25 hours (right) after the irrigation in greenhouse 2.

on line 1 close to the window side. These results showed that spatial variability of underground environmental factors was different in different greenhouses with different dimensions, and also affected by operation of other equipment such as a heater.

Conclusions

This study was conducted to measure and analyze the variation of soil water content, soil temperature and electrical conductivity in greenhouses. Experiments were conducted in two greenhouses using different dimensions, specifications, equipments, and crops. The major results are as follows.

(1) Soil temperature decreased by 1.4°C, and electrical conductivity values were not changed significantly, from morning to afternoon after the irrigation.
(2) Water contents near the pump were greater than other locations. Water content decreased by distance up to 70 m and increased after that, and temperature was greater at middle locations.
(3) Soil water contents on the ridges were lower than

those on the furrows, and the differences were 10.2~18.4%, indicating considerable variability. Lowest (lower) EC values were observed on the furrows and highest (higher) values were observed on the ridges. Temperatures showed relatively uniform over the data collection locations.

(4) Soil in the window side has lower soil water content, and EC and soil temperature were greater than locations close to the center of the greenhouse.

Based on the results, it was concluded that underground soil properties (e.g., soil water content) showed considerable variability by location in the greenhouse and distance from the irrigation pump, and the variability was affected by greenhouse dimension and operation of equipment like a heater. This result would be useful to monitor and control soil environment in the future, and would contribute to variation of sensor installations, number of sensor, and development of control algorithm.

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