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스마트 관개 시스템을 위한 토양 수분 제어시스템 개발

Development of Soil Moisture Controlling System for Smart Irrigation System

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〈Abstract〉

The smart irrigation system using ICT technology is crucial for stable production of upland crops. The objective of this study was to develop a smart irrigation system that can control soil water, depending on irrigation methods, in order to improve crop production. In surface irrigation, three irrigation methods (sprinkler irrigation (SI), surface drip irrigation (SDI), and fountain irrigation (FI)) were installed on a crop field. The soil water contents were measured at 10, 20, 30, and 40 cm depth, and an automatic irrigation system controls a valve to maintain the soil water content at 10 cm to be 30%. In subsurface drip irrigation (SSDI), the drip lines were installed at a depth of 20 cm. Controlled drainage system (CDS) was managed with two ground water level (30 cm and 60 cm). The seasonal irrigation amounts were 96.4 ton/10a (SDI), 119.5 ton/10a (FI), and 113 ton/10a (SI), respectively. Since SDI system supplied water near the root zone of plants, the water was saved by 23.9% and 17.3%, compared with FI and SI, respectively. In SSDI, the mean soil water content was 38.8%, which was 10.8% higher than the value at the control treatment. In CDS, the water contents were greatly affected by the ground water level; the water contents at the surface zone with 30 cm ground water level was 9.4% higher than the values with 60 cm ground water level. In conclusion, this smart irrigation system can reduce production costs of upland crops.

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1. Introduction

For field crops, poor germination due to early season drought and excessive soil water during the growth stage decrease crop productivity. Paddy fields in Korea have high clay contents, resulting in high water holding capacity and poor drainage properties, which causes low production of yield when field crops are grown in paddy fields. Thus, soil water management is important to increase crop yields, because it can minimize crop water stress. In crop field, the water management cost is a big burden due to the repeated installation and disassembly of irrigation and drainage systems.

An automatic irrigation system has been developed for greenhouse cultivation, which is not available to crop field[1]. In Korea, the reduction in farmland area and the aging of farming population has becoming serious; thus, soil specific and automatic water management system should be developed to ensure sustainable production of field crops. This precision irrigation system has a potential to increase profits by utilizing precise information about agricultural resources through sensing and communication technology; water requirement of the crops on growth stage should be determined by a software and the water levels should be monitored and controlled continuously while the crop is growing.

Crop yield and grain quality are sensitive to drought stress. Crop yield fluctuation by drought stress would be intensified due to climate change[2](Kwak et al., 2016). Irrigation during periods of low or no rainfall can significantly increase crop yields.

In subsurface drip irrigation (SSDI), lines containing emitters are buried into a certain depth from soil surface. The SSDI systems are usually installed below the tillage depth, enabling multi-year use. Recently, the interest in SSDI to vegetables, fruit, and field crops has increased around the world in various climate zones due to the conservation of water resources and its convenience for farmers. SSDI has substantial advantages: crop yield improvement ([3] Hunt et al., 2011; [4] Par et al., 2012; [5] Gao et al., 2014), higher water and nutrient use efficiency ([6] Grabow et al., 2006), and less weed germination and growth ([7] Grattan et al., 1990).

Although SSDI is considered to be a very efficient irrigation system, its use has been limited because of the high initial cost, the clogging of emitters, and the difficulty of detecting leakages. In general, the cost of SSDI system depends on installation design; the cost can be reduced by wider lateral spacing of driplines. However, wider spacing causes lower crop yields because the vertical water movement is common in soil. Cotton yield, seed mass, and net returns were significantly greater in narrow dripline spacing (beneath every planted bed, 1 m), compared with alternate furrows (2 m) [8](Enciso et al., 2005). However, no difference was found in crop yield between 1 m and 2 m dripline spacing [9](Camp et al., 1997). Thus, the dripline placement of SSDI system is critical in installation of SSDI. However, no research has been published on the interaction of dripline spacing and position of SSDI system in Korea.

Thus, our objectives of this research were to (1) investigate the effects of SDI, SI, FI system on crop growth and yields and (2) compare crop growth in different lateral spacing and position in SSDI.

2. Materials and methods

2.1 Site Description

Field experiments were conducted at the experimental station of National Institute of Crop Science (35° 29'N 128° 44'E) during crop growing seasons between 2016 and 2017. The experimental station is located in Miryang, Republic of Korea in a temperate climate zone. The annual mean temperature is 13.3° C, and mean annual precipitation is 1,229 mm. The soil is sandy loam with organic matter content of 24.0 g/kg and pH of 7.5. The physicochemical properties of experimental soil are shown in Table 1.

Table 1. Physicochemical properties of the soil

Item		Property
pH		7.5
EC (dS/m)		0.3
OM (g/kg)		24
Available P (mg/kg)		251
Exchangeable Cations (cmol/kg)	K	0.43
	Ca	5.84
	Mg	1.19
PSD (%)	Sand	58.5
	Silt	31.9
	Clay	9.6
Texture		SL

2.2 Automated Irrigation System

The automated irrigation system consisted of wireless sensor units and a wireless information unit, which were linked by radio receivers that allows the transfer of soil moisture and temperature data. A wireless sensor units involved sensors, a microcontroller for data acquisition, and a radio transceiver (ZigBee device). The soil moisture and temperature data from each wireless sensor unit are received, identified, recorded, and analyzed in the wireless information unit.

When the moisture values was less than the threshold value (e.g., 30%), automatic irrigation was activated; a signal was sent to open the solenoid value for supplying water to the soil until its moisture content reached the threshold value. Flow meters were also installed to measure amount of water applied in each irrigation event.

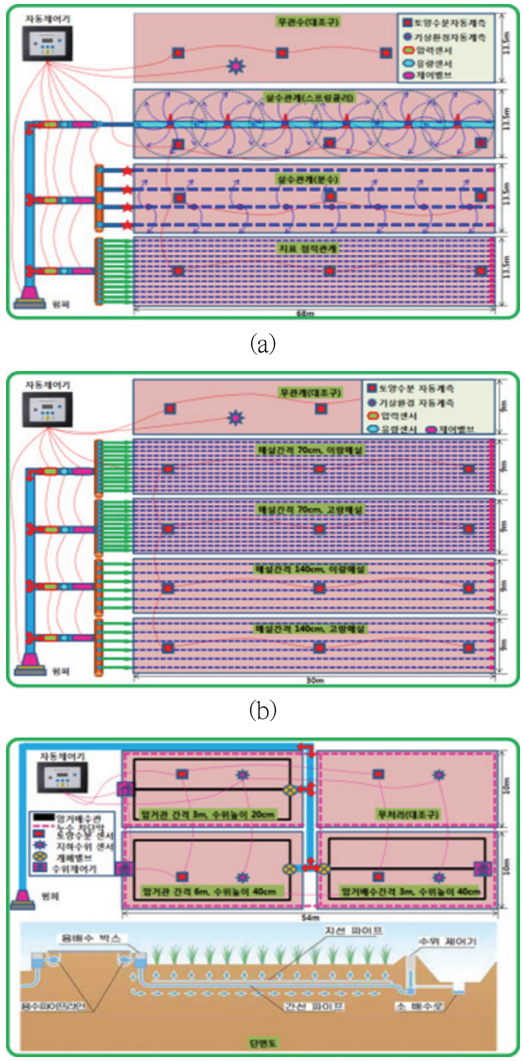
In addition, the wireless information unit has a duplex communication link based on a cellular-Internet interface using general packet radio service (GPRS) protocol

The graphical user interface (GUI) was developed for real-time monitoring soil moisture and temperature data (Fig. 1). The internet connection allows the data inspection in real time on a website, and the data was stored in a database server.

Fig. 1 Graphic user application for monitoring soil moisture and temperature in subsurface drip irrigation

2.3 Irrigation Method

In surface irrigation (Fig. 2(a)), three irrigation methods (sprinkler irrigation (SI), surface drip irrigation (SDI), and fountain irrigation (FI)) were installed on 68 m x 13.5 m fields. In SI, the distance between the sprinklers was 10 m. In SDI and FI, the



(a)

(b)

(c)

Fig. 2 Irrigation Systems; (a) Surface Irrigation, (b) Subsurface Drip Irrigation (SSDI), (c) Controlled Drainage System (CDS)

lateral pipes were laid down 1.2 m and 3 m interval, respectively. An automatic irrigation system regulates a valve to maintain the soil moisture content at 10 cm to be 30%. In subsurface drip irrigation (SSDI) (Fig. 2(b)), the drip lines were installed in a 30 m x 9 m plot at a depth of 20 cm, with integrated dippers every 70 cm or 140 cm under ridge or furrow. In controlled drainage system (CDS) (Fig. 2(c)), the culverts were installed with the spacing of 3 m and 6 m, and it was managed with two ground water levels (30 cm and 60 cm). At these two irrigation systems (SSDI and CDS), soil water status was monitored by wireless sensor network.

2.4 Subsurface Irrigation Experiment

The field experiment of SSDI was conducted with different dripline placement. Five treatments used in this study include the combination of two placements (under ridge or furrow) and two lateral spacing (0.7 m and 1.4 m) of dripline: (a) 0.7 m dripline spacing under ridge (Fig. 3(a)), (b) 0.7 m dripline spacing under furrow (Fig. 3(b)), (c) 1.4 m dripline spacing under ridge (Fig. 3(c)), (d) 1.4 m dripline spacing under furrow (Fig. 3(d)), and (e) rainfed irrigation plot as a control. Driplines (14.2 mm inside diameter) were installed at a depth of 0.3 m below ground, using an install device pulled by a tractor. The pressure compensating emitters were spacing 0.2 m apart, which flow rate was 2.3 L/h. Water was filtered using a disk filter with a 120-mesh screen. The applied water per plot was automatically measured using a flow meter. Irrigation water was supplied from a 20,000 L tank that was automatically replenished by an irrigation pond. Irrigation water use efficiency (IWUE) was calculated from crop yield and applied irrigation amounts as in Eq. 1[10]

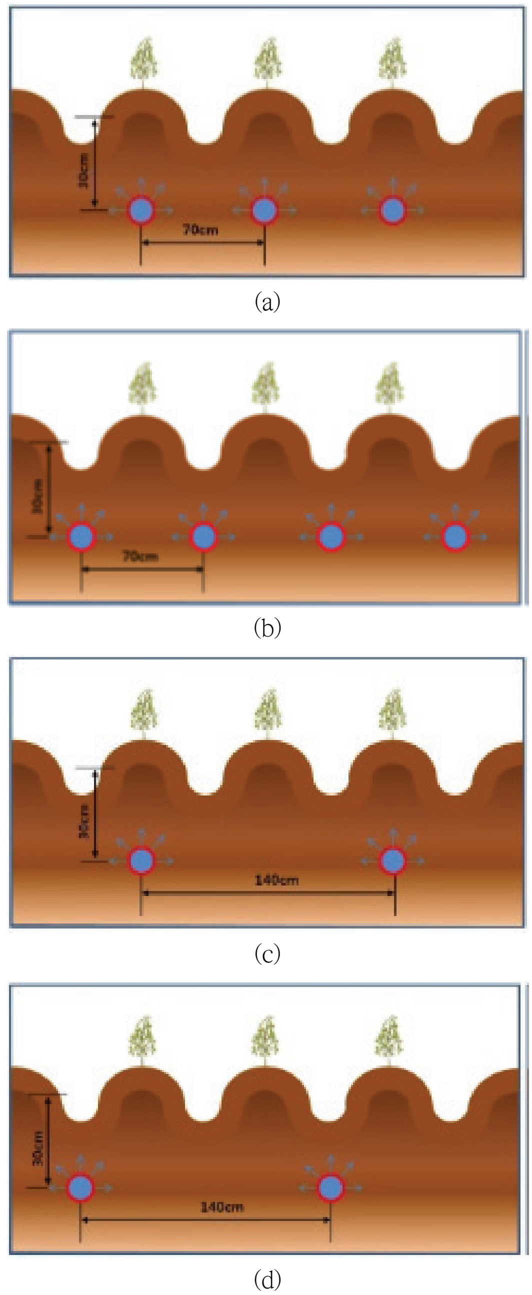


Fig. 3 Treatments with the combination of lateral spacing (0.7 m or 1.4 m) and placement of position (under ridge or furrow)

$$IWUE = \frac{Y_{IRR} - Y_{RI}}{Q_{IRR}} \times 100 \quad (1)$$

where, IWUE (kg/m^3) is irrigation water use efficiency, Y_{IRR} and Y_{RI} (Mg/ha) are crop yield irrigated by treatments and control, respectively. Q_{IRR} (mm) is applied irrigation amount as well.

3. Results and Discussion

3.1 Surface and Subsurface Irrigation

SDI, FI, SI were applied for better production of upland crops. An ICT-based smart irrigation system has been developed and its irrigation performance was evaluated under different irrigation methods. The soil water sensors were installed at 10, 20, 30, and 40 cm depth, so that we can monitor soil water contents in real time. In addition, an irrigation amount measuring system was constructed. Soil water tensions were set to −20 kPa, -30 kPa, and −50 kPa, and crop's growth performance were measured and analyzed to determine the optimum irrigation point. Besides, the soil water contents at root zone was maintained at 30% during the growing season (Fig. 4).

The seasonal irrigation amounts were 96.4 ton/10a (SDI), 119.5 ton/10a (FI), and 113 ton/10a (SI), respectively (Table 2). Since SDI system supplies water near the root zone of the plants, the water was saved by 23.9% and 17.3%, compared with FI and SI, respectively.

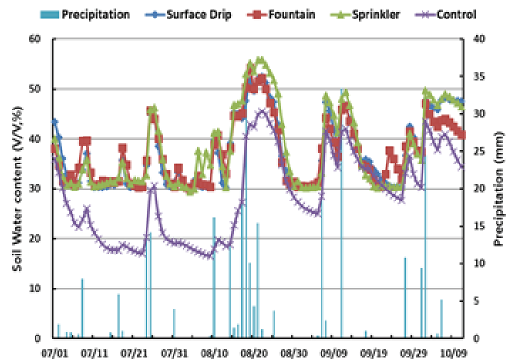


Fig. 4 Soil water contents depending on surface irrigation methods

Table 2. Irrigation amounts depending on irrigation methods

	SDI	FI	SI
Total amount of irrigation (l/ton)	96.4	119.5	113.1
Amount of irrigation per day (l/day)	936.8	1,160.2	1,098.9
Total irrigation time (hr)	17.80	15.43	45.90
Irrigation time per day (min/day)	10.4	9.0	26.7
Irrigation efficiency (%)	91.86	78.92	89.34

In subsurface drip irrigation, the average soil water content was 38.8%, which was 10.8% higher than the value at the control treatment (28%), implying that it provides water effectively (Table 3).

Table 3. Soil water and irrigation amount depending on surface irrigation treatments

	Soil water content (%)	Soil water tension (kPa)	Irrigation amount (L/d)
Under ridge, 70 cm	38.1	-680.2	74.6
Under furrow, 70 cm	38.7	-262.3	67.9
Under ridge, 140 cm	39.8	-57.6	224.7
Under furrow, 140 cm	38.6	-114.5	265.7
Control	28.0	-1,360.4	-

3.2 Controlled Drainage System

A controlled drainage system was developed for land use change from paddy rice cultivation to upland crop. The culverts were buried at 3 m and 6 m spacing. Besides, a ground water level controller was used to maintain the water level at 30 cm and 60 cm. During the crop growth period (June through October), soil water contents and electrical conductivity (EC) were affected by controlled drainage system.

The soil water contents were greatly influenced on the ground water level; the moisture contents at the surface zone (0-10 cm, 10-20 cm) with 60 cm ground water level was 25.3% and 31.6%, which were 9.4% and 8.4% lower than the values with 30 cm ground water level (Table 4). EC was also the lowest at 3 m interval and 60 cm ground water level due to large drainage of water. In addition, the high moisture contents were measured in the narrow culvert spacing.

Table 4. Soil water content and electrical conductivity during the growth stage

Treatment	Soil water content (m^3/m^3)		Electrical conductivity (dS/m)	
	0-10	10-20	0-10	10-20
3 m interval, 30 cm depth	0.322a	0.384a	0.271a	0.439a
6 m interval, 30 cm depth	0.317b	0.336c	0.248c	0.351c
3 m interval, 60 cm depth	0.253d	0.316d	0.128d	0.259d
Control	0.310c	0.353b	0.261b	0.364b
$LSD_{(0.05)}$	0.003	0.003	0.006	0.06

At the high ground water level (30 cm), the soil water content at root zone was no less than 24%; however, at low ground water level (60 cm), this value was down to 12%. In addition, drainage amount was more dependent on ground water level than culvert spacing; the drainage amount at 60 cm ground water level was 14.3 mm/day.

4. Conclusion

The automated irrigation system was found to be feasible for optimizing water resources for agricultural production; it significantly reduced water consumption and saved irrigation water by sufficient moisture content in the root zone.

This irrigation system can be implemented in upland crop field, where water stress in spring is severe. It can also allow cultivation of upland crops in paddy field, where excessive soil water effects at various stages of development on the growth of upland crops. However, this irrigation system should be modified to schedule irrigation of crops depending on growth stage; evapotranspiration is essential for calculating the irrigation water requirement. Besides, all these processes should be possible through a smart phone.

This smart irrigation system can reduce production costs of upland crops, thereby improving food self-sufficiency in Korea.

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