A Study on the drip irrigation system based on CWIS for open-field fruit trees

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***Abstract*— In recent years, interest in and investment in smart farms has continued to grow. One of the most important management elements of these smart farms is irriga-tion. Saving agricultural water used for irrigation is a method that brings excellent environmental and economic effects. In this paper, a drip irrigation system based on CWSI is designed to save agricultural water and improve crop growth envi-ronment through more accurate irrigation. To determine the timing of irrigation, CWSI was calculated using data collected through AWS and infrared cameras, and a random forest model was created to determine the amount and timing of ir-rigation to design a drip irrigation system. To evaluate the performance of the CWSI-based drip irrigation system for open field fruit crops, the irrigation effi-ciency of the existing soil condition-based irrigation system was analyzed based on the change in sap flow volume, and as a result, it was confirmed that the result of this study saves water and meets crop irrigation requirements than the existing soil condition-based irrigation system. If the results of this study are reflected in actual farms, it is expected that it will help reduce farm production costs and im-prove crop growth conditions through saving agricultural water provided for crop growth.**

Keywords*— *CWSI, Open-field fruit tree drip irrigation system, infrared light, Random Forest, Environmental data analysis.

I. INTRODUCTION (*HEADING 1*)

In recent years, there has been an ongoing interest and investment in smart farms. One of the most important factors controlled by these smart farm systems is irriga-tion. According to a report published by the National Water Management Committee in 2021, agricultural water used for such irrigation was 15.9 billion tons, 42% of the total, and 63% of the total by use[1]. In this situation, optimal irrigation system de-sign to save agricultural water has good environmental and economic effects[2]. Agricultural water is one of the main causes of groundwater and surface water pollu-tion when discharged without treatment. Agricultural water that is absorbed into the soil or infiltrated into groundwater contaminates groundwater and surface water be-cause it can contain chemicals that are harmful to non-crop plants, animals, and humans. Agricultural water also contains unnecessary nutrients and chemicals that can cause ecosystem degradation[3]. Preventing this overuse and conserving agricul-tural water through accurate irrigation can help protect ecosystems. Using less water for agriculture prevents unnecessary nutrients and chemicals from entering ground-water and surface water, which helps maintain ecosystem balance[4]. Agricultural water conservation also helps combat climate change. Agricultural water conserva-tion can increase water use efficiency and reduce agricultural greenhouse gas emis-sions[5]. It can also have economic benefits. Saving water in the agricultural sector can reduce costs such as water bills, which can be reinvested to increase agricultural productivity. Therefore, saving agricultural water through accurate irrigation is one of the important measures that can bring environmental and economic benefits[6]. Therefore, this paper aims to calculate the Crop Water Stress Index (CWSI), which can help determine the precise timing and amount of irrigation, to determine the tim-ing and amount of irrigation through linkage with soil environment information, and to design an irrigation system through the drip irrigation method, which can solve the shortcomings of the previously used irrigation methods such as fountain irrigation and sprinkler irrigation, and minimize the consumption of agricultural water.

II. RELATED RESEARCH

A. *Development of Easy Equation for Crop Water Stress Index (CWSIEE) Using the Temperature Difference between Canopy and Air (Tc-Ta) of Fruit Trees*

Yonghun Choi and colleagues developed a simple formula for calculating CWSI using the difference between leaf temperature and air temperature. For this purpose, the research team collected environmental data such as leaf temperature and air temperature, and developed a CWSI calculation formula for open field fruit crops. The researchers of this study suggest that the developed CWSI calculation equation can easily measure CWSI using only basic environmental information such as air temperature and leaf temperature in environments where weather observation is difficult, and that it will help design precision irrigation systems[7]

B. *Water Saving Drip Irrigation Design for Water Melon and Strawberry Under Plastic Film House*

Hee-Rae Cho and colleagues evaluated the optimal irrigation timing considering water utilization efficiency and productivity by applying water according to the irrigated area and soil moisture tension for facility-grown crops and monitoring the amount of water applied by growth period and soil moisture content by depth. As a result of designing the irrigation system through drip irrigation, the research team proved that about 30% of agricultural water can be saved for watermelon crops in the facility[8].

III. EXPERIMENT

A. *CWSI Formulas*

The Crop Water Stress Index is an indicator of crop water status that can be obtained using infrared thermography, which is an easy and rapid method of measuring crop water status. CWSI expresses the water stress of a crop as an index between 0 and 1, and can be measured through non-contact measurement that does not damage the target crop[9]. Data such as leaf temperature, air temperature, humidity, and insola-tion between 10:00 and 15:00 are required to calculate CWSI.

In this paper, we collected data from the testbed to calculate CWSI. During the collection period from February 3 to April 3, 2023, environmental information such as temperature, humidity, air volume, and insolation between 10:00 and 15:00 every day were collected through AWS (Automated Weather Station) at 10-minute inter-vals, and leaf temperature data collection was performed at the same interval through a fixed infrared camera.

The CWSI calculation equation used in this paper to calculate CWSI from the col-lected data is the CWSI calculation equation developed by Jackson et al. (1981), which is shown in Equations 1,2,3[10].

$$CWSI = (((dT - dT\iota)))/((dT\mu - dT\iota)) \quad (1)$$

$$dT\mu = ra\,(Rn - G)\,/\,YCp \quad (2)$$

$$dT\iota = [ra\,(Rn - G) / (YCp)][K/(\sim + K) - VPD / (\sim + K)] \quad (3)$$

In this equation, dT is the difference between leaf temperature and air temperature (° c), dTu is the difference between air temperature and the time when transpiration does not occur due to water stress, and dT1 is the difference between air temperature and leaf temperature when there is no water stress due to sufficient irrigation. G is specific heat of soil (W/M2), ra is air resistance (s/m), Rn is net radiant energy (W/M2), CP is heat capacity (1013 j/kg - °C), Y is air density (kg/M3), k is hygrothermal constant (kPa/ºC), ~ is saturated water vapor pressure to temperature ratio (kPa/ºC), and VPD is vapor pressure difference (kPa).

B. Designing an Irrigation System

Currently, there are two types of irrigation methods used by most open field fruit tree farmers: spray irrigation and underground irrigation. In the case of sprinkler irrigation, water from a water transmission pipe is sprayed through nozzles at various angles and ranges, and depending on factors such as nozzle spacing, spray direction, and water pressure, there is a risk of waterless areas, and depending on the intensity of irrigation, there is a risk of hardening of the ground or loss of topsoil. In the case of underground irrigation, water comes out of the soil from the irrigation pipe buried in the ground and supplies water to the near field of crops, which is less prone to disease and more productive than surface irrigation, but it takes a long time for water to seep up from the underground water supply pipe to the near field, and the loss of agricultural water is large. Therefore, in this paper, drip irrigation was used to conduct the research. Drip irrigation is a watering method that allows water to come out in small amounts by making small water outlets in plastic pipes or tubes. As a water-saving irrigation method, its advantages are that the soil does not harden, there is no loss of topsoil, and there is not much resistance to the movement of water due to the small amount of water flow in the transmission pipe, so it is possible to irrigate a large area uniformly.

Figure 1 shows the decision structure of this study. The irrigation system proposed in this study has the following decision-making process. First, soil environment and meteorological environment data are collected through AWS. In addition, crop leaf temperature data are collected using an infrared camera. A total of 18,000 environmental data and 72,000 leaf temperature data were collected. The collected data was continuously monitored to screen out abnormal data. As a result, 3,001 cases of abnormal data were converted to the average value of the data from 1 hour before to 1 hour after the abnormal data. After that, CWSI was calculated and data was collected through the CWSI calculation formula, and finally, a drip irrigation system that can determine the amount and timing of irrigation through a random forest algorithm was configured to configure an automatic irrigation system.

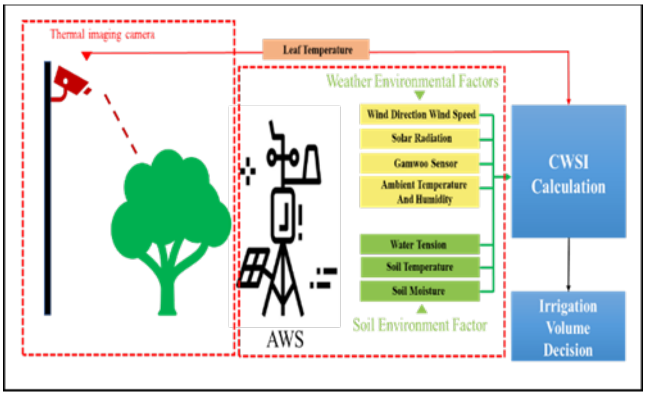

Figure 1. CWSI-based Drip Tube System Structure Diagram

C. Designing a Learning Model

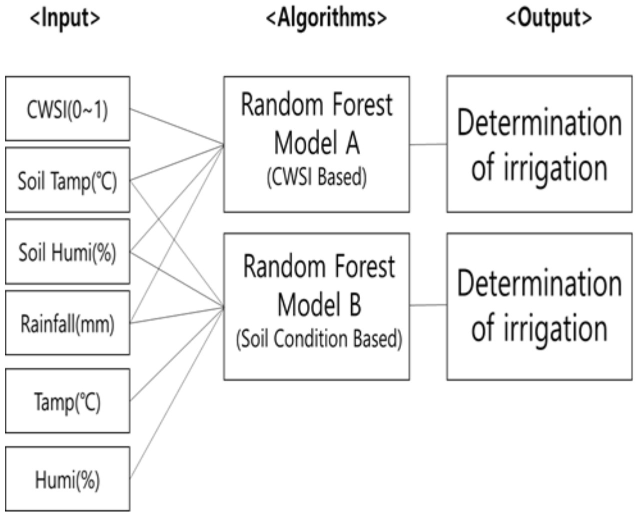

Figure 2. Model Structure Diagram

The algorithm used in this study is an ensemble technique that uses Random Forest to train multiple decision trees. Precipitation, soil humidity, CWSI, etc. were selected as input variables, and for model training, matching between environmental data and leaf temperature data collected at the same time was performed first for all collected data. As a result, 18,000 environmental data were matched with 72,000 leaf temperature data collected through four infrared cameras to form a training dataset consisting of 72,000 data, of which 30% (21,600) were utilized as a test set for performance verification. In the learning process, the training set was divided into 80% (40,230) and the validation set 20% (10.080) by performing cross-validation to optimize the hyperparameters.

Figure 2. shows the structure of the finalized model. Model_A is a model for CWSI-based drip irrigation decision-making, and Model_B is a model for soil condition-based irrigation decision-making. Table 1 shows the main hyperparameters and the optimization search intervals. The process of training the model and evaluating its performance with randomly selected combinations of the optimization exploration intervals was repeated 500 times, and the best performing hyperparameter combination was derived. The resulting hyperparameter combinations are shown in Table 2.For papers with more than six authors: Add author names horizontally, moving to a third row if needed for more than 8 authors.

TABLE I. SEARCH RANGES FOR HYPERPARAMETER OPTIMIZATION

Hyperparameter	Range
n_estimators	3, 10, 100, 1000, 2000
max_features	auto, sqrt, log2
max_depth	None, 2, 4, 8, 16, 32, 64,
criterion	squared_error, absolute_error, poisson
min_samples_leaf	2 ,4, 6, 8, 12,
min_samples_split	2 ,4, 6, 8, 16,

TABLE II. OPTIMIZED HYPERPARAMETERS

Hyperparameter	Model_A	Model_B
n_estimators	1000	1500
max_features	4	2
max_depth	2	2
criterion	Log2	Sqrt
min_samples_leaf	32	None
min_samples_split	Squared_error	poisson

D. Evaluating Irrigation System Performance

In order to evaluate the performance of the CWSI underground irrigation system for open field fruit crops, the CWSI underground irrigation system was compared to the previously designed soil condition-based underground irrigation system based on the temperature, humidity, soil humidity, and soil temperature data collected under the same conditions, and the performance evaluation of the CWSI underground irrigation system and the soil condition-based irrigation system was conducted based on the amount of sap flow change.

By analyzing the graph, it can be seen that the soil moisture and sap flow changes are different for the same crop in the same soil.

Figure 3 is a graph of soil moisture and sap flow changes in a soil condition-based irrigation system. In this case, the soil moisture is maintained at the average value by irrigating based on soil humidity, but the difference in the sap flow change of the crop by irrigating regardless of the moisture requirement of the crop shows a range of 15% from the average value.

Figure 4 is a graph of soil moisture and sap flow variation in a CWSI-based drip irrigation system. In this case, it can be seen that the proper soil moisture level is maintained by topsoil moisture supply, which is an advantage of the drip irrigation system. In addition, the change in sap flow of the crop by irrigating based on CWSI is also maintained at a constant value in the range of 8.75% from the average value. In addition, the difference between the two irrigation systems can be seen in the average irrigation amount during the study period. Visually, the crops were almost identical during the study period. However, in terms of the amount of water applied during the crop growth process, the soil condition-based irrigation system averaged 112 L per week, while the CWSI-based irrigation system averaged 89.7 L per week, showing a very good effect in terms of agricultural water saving.

Based on these results, it can be seen that designing an irrigation system based on crop CWSI information can provide an optimal irrigation environment for crops rather than the existing method of irrigating through soil moisture and weather conditions.

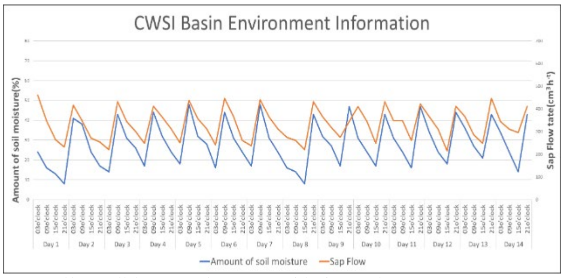

Figure 3. Soil conditions environmental information

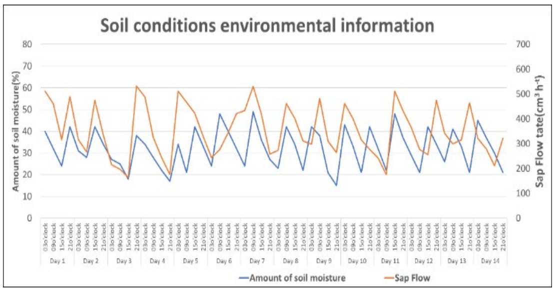

Figure 4. CWSI Basin Environment Information

IV. CONCLUSION

In this study, we designed an underground irrigation system for open field fruit crops. To determine the timing of irrigation, CWSI was calculated using data collected through AWS and infrared cameras, and a RandomForest model was created to determine the amount and timing of irrigation based on CWSI data and collected environmental data to design an underground irrigation system.

For the performance evaluation of the CWSI-based drip irrigation system for open field fruit crops, a comparative evaluation with the existing soil condition-based irrigation system was conducted. To evaluate the irrigation efficiency, the soil moisture and sap flow rate changes were analyzed by graphing, and as a result, it was confirmed that the result of this study saves irrigation water and meets crop irrigation requirements than the existing soil condition-based irrigation system.

If the results of this study are reflected in actual farms, it is expected to help reduce farm production costs by saving agricultural water provided for crop growth through optimal irrigation decision making, and it is expected to improve crop growth in the crop growth part.

If further research is conducted, it is expected that the current research results can be further advanced as an irrigation system for specific crops if sufficient data on greenhouse crops and cereals such as rice are collected in the future, as the current research system can only perform accurate irrigation for open field fruit crops.

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