Development of a Data Acquisition System for the Long-term Monitoring of Plum (Japanese apricot) Farm Environment and Soil

Tangina Akhter1, Mohammad Ali1, Jaeyoon Cha2, Seong-Jin Park1, Gyeang Jang1, Kyu-Won Yang3, Hyuck-Joo Kim1*

1Department of Industrial Machinery Engineering, Sunchon National University, 225 Jungang-ro, Suncheon, Jeonnam 57922, Republic of Korea
2Department of Food Science and Nutrition, Dong-A-University, 37 Nakdong-daero 550 beon-gil, Saha-gu, Busan, 49315, Republic of Korea
3Major in Bio-Industrial Machinery Engineering, Kyungpook National University, 80 Daehakro, Bukgu, Daegu 41566, Republic of Korea

Received: October 6th, 2018; Revised: November 17th, 2018; Accepted: November 22nd, 2018

Purpose: To continuously monitor soil and climatic properties, a data acquisition system (DAQ) was developed and tested in plum farms (Gyewol-ri and Haechang-ri, Suncheon, Korea). Methods: The DAQ consisted of a Raspberry-Pi processor, a modem, and an ADC board with multiple sensors (soil moisture content (SEN0193), soil temperature (DS18B20), climatic temperature and humidity (DHT22), and rainfall gauge (TR-525M)). In the laboratory, various tests were conducted to calibrate SEN0193 at different soil moistures, soil temperatures, depths, and bulk densities. For performance comparison of the SEN0193 sensor, two commercial moisture sensors (SMS-BTA and WT-1000B) were tested in the field. The collected field data in Raspberry-Pi were transmitted and stored on a web server database through a commercial communications wireless network. Results: In laboratory tests, it was found that the SEN0193 sensor voltage reading increased significantly with an increase in soil bulk density. A linear calibration equation was developed between voltage and soil moisture content depending on the farm soil bulk density. In field tests, the SEN0193 sensor showed linearity (R = 0.76 and 0.73) between output voltage and moisture content; however, the other two sensors showed no linearity, indicating that site-specific calibration is important for accurate sensing. In the long-term monitoring results, it was observed that the measured climate temperature was almost the same as website information. Soil temperature information was higher than the values measured by DS18B20 during spring and summer. However, the local rainfall measured using TR 525M was significantly different from the values on the website. Conclusion: Based on the test results obtained using the developed monitoring system, it is thought that the measurement of various parameters using one device would be helpful in monitoring plum growth. Field data from the local farm monitoring system can be coupled with website information from the weather station and used more efficiently.

Keywords: Calibration, Monitoring, Plum, Raspberry pi, Sensors

Introduction

Plum (Prunus mume) is a highly valued stone fruit with physiological functions for quick recovery from fatigue, hypertension, liver ailments, and diabetes (Shi et al., 2009; Ali et al., 2017). The cultivated area of plums in the Republic of Korea was quite small, about 156 ha, in 1980; however, it started to increase from 1990 (Lee et al., 2011). Plum production in 2003 was 77,438 tons from an area of 6,452 ha, but the cultivation area increased to 10380 ha in 2017 and is expected to increase further (KOSIS, 2018). Owing to an increase in the cultivation area, plum prices are dropping consistently. Hence, it is necessary to improve the plum growing method for increasing farm revenue. In this context, a plum growth
monitoring system could help in improving the growing. The relevant properties of soil include soil moisture, clay content, organic matter content, nutrient availability, temperature, salinity, pH, and bulk density (Li et al., 2014). Plum growth is highly sensitive to water deficits, which could be related to the climatic parameters include rainfall, temperature, humidity. It was found that deficit irrigation reduced the fruit weight by 10% to 12% (Intrigliolo and Castel, 2006). Heat accumulation of full bloom for 30 days is an important factor for the development of stone fruit after harvesting (Day et al., 2008). After full bloom, the effect of 40 days in fruit growth was significantly affected by the temperature of the growth environment (Warrington et al., 1999). If the soil temperature is high, no flower buds would be formed in citrus fruits (Poerwanto et al., 1989). High relative humidity levels and a lack of air circulation inhibit evaporation from the plant and its ability to draw nutrients from the soil. Therefore, monitoring all the parameters is important to achieve good plum quality as well as a good yield. However, it is very difficult to routinely monitor the farm land to gather relevant property data.

Therefore, it might be easier to monitor soil and environmental parameters using IoT technologies. The advantages of wireless sensor networks can be exploited in agricultural applications to acquire precise spatial and temporal knowledge about farm areas. However, there are several factors that have to be considered when selecting a sensor for network applications (Bogena et al., 2007). In order to maximize the lifetime of a network, sensors should be economical and reasonably robust. Some sensors are being used in applications for which they are not suited, producing results that have little correlation with actual field conditions. However, different factors in the field, such as rocks, roots, variation in the clay content, temperature, soil compaction, and salinity often result in the manufacturer’s calibration being inapplicable. This indicates that a thorough evaluation of sensor performance and site-specific calibration are highly needed (Hignett and Evett, 2008).

A wireless sensor network system was developed to monitor climate changes using an Arduino, a Zigbee, and a Raspberry pi equipped with temperature and humidity sensors (RHT03) (Ferdous and Li, 2014). Another device was developed using a multifunctional data acquisition board (MDA320) and ZigBee; this device could acquire data on multiple soil properties in wheat fields (Li et al., 2014). However, considering soil and climatic properties, using one device would be easier and more cost effective for monitoring any fruit/crop growth.

Therefore, the objective of this study is to develop and deploy a data acquisition system (DAQ) for monitoring the real-time situation in a plum field. The system was composed of a Raspberry Pi single board computer, a modem, an ADC board, and climate and soil parameter sensors. To evaluate the performance of the DAQ, extensive lab and field tests were conducted on all the sensors. The plum field soil and environment were also investigated for monitoring purposes.

**Materials and Methods**

**DAQ system overview**

A data acquisition system was deployed for measuring soil and climate properties and establishing wireless communication between the sensor node and central node, which enables real-time monitoring of farm information. Four sensor nodes (soil moisture content, soil temperature, atmospheric temperature and humidity, and rainfall) were connected to the Raspberry Pi single board computer to acquire soil and climatic data. The data collected on the Raspberry Pi was transmitted and stored on a web server database using a commercial wireless network. The database was created on MySQL using the phpMyAdmin software tool. The localhost was linked to the Raspberry Pi Python program for data collection (Fig. 1).

**The DAQ system and sensors**

The DAQ consisted of a single board microcomputer, Raspberry Pi B+, a MCP3008 ADC board, and sensors that

![Figure 1. Overall schematic diagram of the DAQ system for soil and climatic parameter monitoring.](image-url)
gather data on climatic temperature and humidity, soil temperature and moisture content, and amount of rainfall.

The developed DAQ system is shown in Figure 2. The climatic temperature and humidity sensors, soil temperature sensor, and rainfall gauge were directly connected to the Raspberry Pi board through digital GPIO ports and the soil moisture sensor was connected to the board through an AD converter (Model name: MCP 3008, Adafruit, New York city, USA).

The Wi-Fi unit (Model: NP40K, NEXPRING, Gyeonggi-do, Republic of Korea) was connected with Raspberry Pi for data collection. The ambient temperature and humidity sensor consists of a single chip and is a fully calibrated digital relative temperature and humidity sensor (Model: DHT22, DFROBOT, Shanghai, China; Fig. 2 (d)). The soil temperature sensor (Model: DS18B20, DFROBOT, Shanghai, China; Fig. 2 (c)) provides readings over a single wire interface across a range of 0–5.5 V. The soil moisture sensor (Model: SEN0193, DFROBOT, Shanghai, China; Fig. 2 (b)) measures the soil moisture content by capacitive sensing. The output value range of this sensor was 0–3.3 V. Also was used as a Wi-Fi unit.

In order to compare the performance of the soil moisture sensors, other soil moisture sensing devices were also employed. Vernier soil moisture sensors (SMS-BTA, Vernier Software and Technology, Beaverton, USA) were set up in the Gyewol and Haechang farms. In addition, a Wet sensor (WT-1000B, Mirae sensor, Seoul, Republic of Korea) was set up in the Gyewol farm. The specifications of these sensors are listed in Table 1 and Table 2.

![Figure 2. The developed DAQ. (a) Wi-Fi unit, (b) capacitive soil moisture sensor, (c) ambient temperature and humidity sensor, (d) soil temperature sensor, (e) rainfall gauge sensor, (f) ADC converter, and (g) Raspberry pi.](image)

<table>
<thead>
<tr>
<th>Table 1. Specifications of the moisture sensors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensors</td>
</tr>
<tr>
<td>Manufacturer</td>
</tr>
<tr>
<td>Sensor type</td>
</tr>
<tr>
<td>Measuring range</td>
</tr>
<tr>
<td>Output voltage</td>
</tr>
<tr>
<td>Operating temperature</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 2. Specifications of the temperature and humidity sensors and rain gauge sensor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sensors</td>
</tr>
<tr>
<td>Manufacturer</td>
</tr>
<tr>
<td>Sensor type</td>
</tr>
<tr>
<td>Measuring range</td>
</tr>
<tr>
<td>Output voltage</td>
</tr>
<tr>
<td>Accuracy</td>
</tr>
</tbody>
</table>
Sensor calibration (soil moisture and temperature sensors)

Measurement of soil moisture with respect to bulk density, depth, and soil temperature

The soil moisture content reading can vary depending on the soil bulk density, temperature, and depth (Gong et al., 2003). Therefore, the performance of the soil moisture sensor (SEN0193) was evaluated at different bulk densities, depths, and temperatures. The measurement methods are explained below:

1. Soil bulk density: The soil bulk densities of the Gyewol and Haechang farms were examined using a core sample method. Before core sampling, 1.5 cm of the upper soil was removed. Soil samples were collected with core at three different sites with a moisture sensor located nearby at a depth of 10 cm. The collected soil was brought to the laboratory and its bulk density was evaluated. The results are shown in Table 4. After calculating the bulk density, the soil samples were further converted into soil specimens with 4 different bulk densities (0.9, 1.1, 1.3 and 1.5 g/cm$^3$). Differences in bulk density were achieved by filling the cylinder with an equal volume with different mass of soil.

2. Soil depth: In the case of plum trees, about 60% of their roots are distributed at a depth of 0 to 10 cm and the maximum length of root shoots is about 30 cm (Yoon, 2013). Taking this point into consideration, the moisture sensor was inserted at a four-layer soil depth. At first, the SEN0193 sensor was set vertically at a depth of 0 to 10 cm and then horizontally at depths of 10, 15, and 20 cm at a temperature of 19 to 22°C. The soil bulk density was set at 1.3 g/cm$^3$ for the Gyewol soil and 1.1 g/cm$^3$ for the Haechang soil.

3. Soil temperature: Soil moisture was measured at various soil temperatures, viz. warm (19 to 22°C), cold (8 to 10°C), and frozen (−5°C), at a depth of 10 cm. Different soil-temperature samples were prepared using a temperature control chamber (VB-150 B, Vision Biotech, Incheon, Republic of Korea).

The experiment were replicated four times at four different depths and bulk density with three different temperature. Analysis of variance (ANOVA) was performed using the Minitab Statistical Software Release 13.20 (Minitab Inc., State college, PA, USA). After each sensor was read, the moisture content of the soil samples was measured using an oven-dry method at 105°C over 24 h. The following equation (equation (1)) was employed.

\[
\text{Moisture content (\%)} = \frac{\text{Total weight} - \text{Dried soil weight}}{\text{Total weight of soil}}
\]

Soil moisture sensor calibration

First, the SEN0193 soil moisture sensors were calibrated. In order to investigate the accuracy of the measurement in distributed soils, loamy sand soil samples were collected by sampling auger and their moisture contents were measured using the oven-dry method. This method was employed on the soils obtained from the Gyewol and Haechang plum farms. The soil samples were collected at a depth of 10 cm below the ground.

Soil samples from the two plum farms (Gyewol and Haechang) were dried in the oven and then water was added to create moisturized soil samples (moisture content in the range of 10% to 50%). After moisturizing, the bulk density of the soil samples was set as 1.3 g/cm$^3$ (Gyewol) and 1.1 g/cm$^3$ (Haechang). The measuring depth was 0 to 10 cm and the ambient room temperature was 19 to 22°C. Figure 3 shows the soil moisture sensor calibration.
in the soil sample and the DAQ system for moisture reading. The result data were shown in Table 3.

**Verification of the soil and climate temperature sensors**

In order to check the accuracy of the DS18B20 and DHT 22 sensors, temperature was measured at three different conditions, viz. low (−10 to 0°C), middle (around 25°C), and high (around 45°C) conditions, in a temperature control chamber (VB-150 B, Vision BioTech, Incheon, Republic of Korea). For reference, the soil temperature was checked using a thermometer (−20 to 120°C). Later, soil temperature readings were recorded using the DS18B20 sensor and climate temperature readings were recorded by the DHT 22 sensor. The bulk density was adjusted to 1.3 g/cm³ for the Gyewol farm soil and 1.1 g/cm³ for the Haechang farm soil; the measuring depth of the soil temperature sensor was 10 cm (Fig. 4).

### Table 3. Statistical table with different soil moisture contents (%), wet basis

| Soil moisture (%), w.b. | No. of observations | Gyewol farm | | Haechang farm | |
|------------------------|---------------------|-------------|-----------------|-----------------|
|                        |                     | Mean voltage (V) | Standard deviation | Mean voltage (V) | Standard deviation |
| 11                     | 3                   | 3.255        | 0.006            | 2.694           | 0.003 |
| 13                     | 3                   | 3.065        | 0.003            | 2.643           | 0.003 |
| 15                     | 3                   | 2.869        | 0.002            | 2.403           | 0.003 |
| 17                     | 3                   | 2.674        | 0.005            | 2.362           | 0.004 |
| 19                     | 3                   | 2.563        | 0.005            | 2.317           | 0.002 |
| 21                     | 3                   | 2.432        | 0.004            | 2.256           | 0.002 |
| 23                     | 3                   | 2.289        | 0.002            | 2.082           | 0.003 |
| 25                     | 3                   | 2.150        | 0.003            | 1.956           | 0.004 |
| 27                     | 3                   | 1.999        | 0.005            | 1.869           | 0.004 |
| 29                     | 3                   | 1.903        | 0.005            | 1.627           | 0.002 |
| 31                     | 3                   | 1.761        | 0.002            | 1.509           | 0.004 |
| 33                     | 3                   | 1.659        | 0.002            | 1.337           | 0.002 |
| 35                     | 3                   | 1.580        | 0.001            | 1.212           | 0.002 |
| 37                     | 3                   | 1.497        | 0.002            | 1.160           | 0.007 |
| 39                     | 3                   | 1.416        | 0.002            | 0.983           | 0.003 |
| 41                     | 3                   | 1.322        | 0.002            | 0.935           | 0.006 |
| 43                     | 3                   | 1.129        | 0.004            | 0.773           | 0.006 |
| 45                     | 3                   | 1.000        | 0.004            | 0.709           | 0.006 |
| 47                     | 3                   | 0.775        | 0.004            | 0.612           | 0.004 |
| 49                     | 3                   | 0.679        | 0.002            | 0.483           | 0.005 |
| 51                     | 3                   | 0.585        | 0.005            | 0.387           | 0.005 |

**Field application of DAQ**

**General explanation of the plum farm monitoring system**

A monitoring station was constructed to monitor soil and weather conditions in specific fields. Using this station, soil and weather data was collected from two plum farms (Gyewol and Haechang sites) in the city of Suncheon in 2017 and 2018. Field tests were conducted using the DAQ and sensors. Soil moisture was measured using the capacitive soil moisture sensor SEN0193. SMS-BTA and WT-1000B devices were also set up for a comparative study. This structure was made of wood and was 2 m in height. The part in contact with the ground was fixed with wood across an area of about 1.2 m²; all the soil sensors were placed in this area. The DAQ weatherproof control box was fixed with a wooden structure with a steel component in the middle part. Connections for all the sensors were generated from this part for monitoring the soil and climate. At the upper part, which was intended for weather monitoring, atmospheric temperature and humidity sensors were set up at a height of 1.5 m from the ground. A rain gauge sensor was set up with a wooden structure at a distance of ~1 m from the weather station (Fig. 5). Soil property sensors were buried at a
depth of 10 cm for measuring soil temperature and moisture content.

**Field performance test of the moisture sensors**

Two moisture sensors (SEN0193 and SMS-BTA) were installed at the two sites during the summer of 2017. A WT-1000B sensor was used to collect data manually once every week. The sensors were installed at a distance of 25 to 30 cm from each other underneath a plum tree at a uniform depth of 10 cm (SEN0193, WT-1000B) and 15 cm (SMS-BTA). The sensors were installed by digging a shallow trench and inserting them vertically (SEN0193) and horizontally (SMS-BTA) into the wall and then backfilling the trench. Simultaneously, soil samples near the sensor locations were taken by soil auger and taken directly to a laboratory to measure the moisture content by the oven-dry method. The soil moisture data provided by the sensors was compared to the oven-dry results for evaluating the accuracy of the sensors.

**Long-term monitoring of soil and environment properties**

In order to analyze the relationship between farm information received from the developed system and the local information on climate temperature, ground temperature and rainfall data were collected from the Suncheon weather station of the Korea Meteorological Administration.

The soil texture and geographic conditions of the two agricultural fields are presented in Table 4. The soil textures were examined by particle-size analysis.

### Results and Discussion

**Sensor verification in laboratory**

In laboratory tests, soil moisture sensor reading with different soil temperature, bulk density and measuring depth was tested; further, all the sensors (SEN0193, DHT22, DS18B20) were calibrated and verified.

**Soil moisture sensor reading (SEN0193) at various soil temperatures**

Temperature can affect moisture sensors by directly influencing the sensor circuitry, the dielectric constant of water, and water-soil interactions. Hence, it is necessary that the SEN0193 soil moisture sensor outputs show

---

**Table 4. Geographical conditions and composition at the two sites**

<table>
<thead>
<tr>
<th>Site</th>
<th>Latitude (N)</th>
<th>Longitude (E)</th>
<th>Soil EC (dS/m)</th>
<th>Soil bulk density (g/cm³)</th>
<th>Soil composition</th>
<th>Soil type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Sand (%)</td>
<td>Silt (%)</td>
</tr>
<tr>
<td>Gyewol</td>
<td>35°03´</td>
<td>127°25´</td>
<td>0.21-0.77</td>
<td>1.22-1.3</td>
<td>82.22</td>
<td>17.69</td>
</tr>
<tr>
<td>Haechang</td>
<td>34°54´</td>
<td>127°32´</td>
<td>0.12-0.50</td>
<td>1.1-1.18</td>
<td>81.82</td>
<td>18.03</td>
</tr>
</tbody>
</table>

---

**Figure 5.** (a) Plum farm monitoring system. Three sensors in plum farm: (b) SEN0193 sensor covered with plastic box to avoid rain water, (c) SMS-BTA and (d) WT-1000B.
comparable characteristics at different temperatures. Table 5 shows the results of soil moisture readings at different temperatures at a depth of 10 cm in the 1.3 g/cm³ Gyewol soil and 1.1 g/cm³ Haechang soil.

The voltage reading difference at three different temperatures with four replications were varied in the range of 0.01–0.06 V. In the Gyewol soil, a 0.01 V difference was observed at different moisture contents under warm and cold conditions, which means that the soil moisture increased at lower temperatures. Nevertheless, according to ANOVA analysis, there is no significant difference between the sensor readings at different soil temperatures. In the case of the Haechang farm soil, the soil moisture was independent of the changes in temperature. According to Gong et al. (2003), the moisture content reading of a TDR moisture sensor could be decreased by increasing the ambient temperature. Other reports suggest that temperature changes exerted little effect on the ECH₂O soil moisture sensor (Campbell, 2001). Therefore, it can be stated that there were no statistically significant differences at different temperatures. These results indicate that temperature correction is not necessary for soil moisture content measurement.

### Soil moisture sensor reading (SEN0193) at different soil bulk densities

As expected, at a 10 cm depth and temperature of 19–22°C, the soil moisture content increased as the bulk density increased (Table 6). According to Gong et al. (2003), at different moisture contents, the dielectric permittivity of the soil increased with an increase in the soil bulk density. Among the soil samples, the reading difference was found to be 0.04 to 0.37 V at different bulk densities with four replications. The moisture content of the standard sample would be underestimated at lower densities and overestimated at higher densities. From statistical analysis, it was found that there was a significant difference between the sensor readings at different bulk densities and moisture contents. The soil moisture voltage reading at a bulk density of 0.9 g/cm³ was significantly different from that at 1.5 g/cm³. On the other hand, the voltage readings at 1.1 and 1.3 g/cm³ were not significantly different. This suggests that some caution is necessary when using SEN0193 as the soil sensor. Therefore, soil moisture sensor calibration was carried out depending on the soil bulk density of the specific plum farm in which soil moisture sensor was set.

### Table 5. Voltage readings at different temperatures

<table>
<thead>
<tr>
<th>Site</th>
<th>-5°C</th>
<th>8-10°C</th>
<th>19-22°C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gyewol</td>
<td>2.98 ±0.0061&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.98±0.0026&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.99±0.0032&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>2.56±0.0026&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.58±0.0026&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.59±0.0047&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>2.11±0.0040&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.11±0.0016&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.12±0.0045&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td>Haechang</td>
<td>2.75±0.0042&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.82±0.0032&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.74±0.0040&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>2.50±0.0032&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.49±0.0040&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.51±0.0040&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
<tr>
<td></td>
<td>1.99±0.0040&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.02±0.0032&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.96±0.0032&lt;sup&gt;b&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

All the results are expressed as mean ± standard deviation (n = 4). Statistical significance (p < 0.05) was analyzed using a one-way ANOVA test (Tukey’s multiple range test).<sup>a</sup> Statistically significant difference compared to the baseline.

### Table 6. Voltage readings at different bulk densities

<table>
<thead>
<tr>
<th>Site</th>
<th>Bulk density (g/cm³)</th>
<th>0.9</th>
<th>1.1</th>
<th>1.3</th>
<th>1.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gyewol</td>
<td>3.27±0.0113&lt;sup&gt;a&lt;/sup&gt;</td>
<td>3.23±0.0048&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.99±0.0026&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.89±0.0016&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>3.06±0.0055&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.75±0.0040&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.59±0.0026&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.51±0.0018&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.53±0.0042&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.27±0.0080&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.12±0.0046&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.93±0.0016&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td>Haechang</td>
<td>2.96±0.0071&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.74±0.0048&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.61±0.0032&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.59±0.0016&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.88±0.0048&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.51±0.0040&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.48±0.0040&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.22±0.0032&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2.07±0.0061&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.96±0.0026&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.89±0.0026&lt;sup&gt;a&lt;/sup&gt;</td>
<td>1.70±0.0016&lt;sup&gt;b&lt;/sup&gt;</td>
<td></td>
</tr>
</tbody>
</table>

All the results are expressed as mean ± standard deviation (n = 4). Statistical significance (p < 0.05) was analyzed using a one-way ANOVA test (Tukey’s multiple range test).<sup>a</sup> <sup>b</sup> Statistically significant difference compared to the baseline.
Soil moisture sensor reading (SEN0193) at various soil depths

In order to study the relationship between soil moisture content and measuring depth, soil moisture sensor readings were taken at four different measuring depths of 10, 15, and 20 cm in the temperature range of 19 to 22 °C with four replications.

As shown in Table 7, the moisture content readings of the soils at different depths were not uniform, but not statistically different. These results indicate that a measuring depth of 10 to 20 cm has some effect on the soil moisture reading. Further, in plum farm soil, about 60% of the rootstocks, which absorb nutrients, are distributed at a 10 cm depth. Therefore, a depth of 10 cm was considered for placing the sensors.

From the above described results, it could be inferred that the soil temperature and measuring depth had no significant effect on the SEN0193 sensor reading. However, if the bulk density is either higher than 1.3 g/cm³ or lower than 0.9 g/cm³, the soil moisture content reading varies in a corresponding manner. Therefore, for sensor calibration, the bulk density of the Gyewol farm soil was fixed at 1.3 g/cm³ and that of the Haechang farm soil was fixed at 1.1 g/cm³; these values were similar to the actual soil bulk density at the two farms.

Calibration equations for the moisture sensor (SEN0193)

The calibration results of the sensor output voltages of the two types of soil are shown in Figure 6. A linear relationship was found between the sensor output voltage and soil moisture at both sites; the calibration equations are shown in Table 8. Based on the obtained

<table>
<thead>
<tr>
<th>Site</th>
<th>Bulk density (g/cm³)</th>
<th>Measuring depth (cm)</th>
<th>10. horizontally</th>
<th>15. horizontally</th>
<th>20. horizontally</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gyewol</td>
<td>1.3</td>
<td>2.86±0.0041</td>
<td>2.99±0.0026</td>
<td>2.98±0.0018</td>
<td>2.89±0.0016</td>
</tr>
<tr>
<td>Gyewol</td>
<td>1.3</td>
<td>2.51±0.0040</td>
<td>2.59±0.0041</td>
<td>2.58±0.0053</td>
<td>2.56±0.0032</td>
</tr>
<tr>
<td>Gyewol</td>
<td>1.3</td>
<td>2.01±0.0026</td>
<td>2.12±0.0045</td>
<td>2.11±0.0018</td>
<td>2.10±0.0016</td>
</tr>
<tr>
<td>Haechang</td>
<td>1.1</td>
<td>2.40±0.0032</td>
<td>2.74±0.0048</td>
<td>2.71±0.0048</td>
<td>2.69±0.0032</td>
</tr>
<tr>
<td>Haechang</td>
<td>1.1</td>
<td>2.30±0.0018</td>
<td>2.51±0.0041</td>
<td>2.52±0.0041</td>
<td>2.50±0.0016</td>
</tr>
<tr>
<td>Haechang</td>
<td>1.1</td>
<td>1.82±0.0026</td>
<td>1.96±0.0026</td>
<td>1.97±0.0045</td>
<td>1.92±0.0018</td>
</tr>
</tbody>
</table>

All the results are expressed as mean ± standard deviation (n = 4). Statistical significance (p < 0.05) was analyzed using a one-way ANOVA test (Tukey's multiple range test).

<table>
<thead>
<tr>
<th>Site name</th>
<th>Equation</th>
<th>R²</th>
<th>Bulk density (g/cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gyewol</td>
<td>y = -15.58x+59.681</td>
<td>0.99</td>
<td>1.3</td>
</tr>
<tr>
<td>Haechang</td>
<td>y = -15.911x+55.674</td>
<td>0.98</td>
<td>1.1</td>
</tr>
</tbody>
</table>
results, the soil bulk density was set at 1.3 g/cm$^3$ for the Gyewol farm soil and 1.1 g/cm$^3$ for the Haechang farm soil. The measuring depth was set at 10 cm for both soils.

Using these calibration equations for the two sites, the measured sensor output data could be used to record soil moisture content. The correlation coefficients of the graphs suggest that the gravimetric soil moisture content measured by the capacitive SEN0193 sensor increases linearly in the soil moisture range of 10% to 50% (w.b.). Therefore, the soil moisture contents of the plum farms include a voltage reading (V, X) and soil moisture (% Y).

**Accuracy evaluation of the soil temperature and climatic temperature sensors**

The differences between the controlled and reading temperatures are shown in Figure 7.

Regression analysis showed that the $R^2$ value of the soil temperature sensor was 0.99. The temperature reading error of DHT22 was 0.15%, which means that the error was within the manufacturer’s specification range (±2% and ±0.5°C). This result suggests that the accuracy of DS18B20 and DHT22 sensors is good for field applications.

**Field performance of moisture sensors**

The soil moisture content measurement results in the two farms are illustrated in Figure 8.

In Figure 8, it can be seen the readings of SEN0193, SMS-BTA, and WT-1000B show different moisture content values for the same sample. However, the errors of SEN 0193, SMS-BTA, and WT-1000B relative to the reference value (oven-dry method) were 6.2%, 16.9%, and 12.2% for the Gyewol farm, respectively, and 4.3%, 10.0%, and 9.5% for the Haechang farm, respectively. The reading errors of commercial SMS-BTA and WT-1000B were 2.7 and 2.0 times higher, respectively, for the Gyewol farm and 2.4 and 2.2 times higher, respectively, for the Haechang farm when compared to those of SEN0193 that was calibrated to the plum farm soils. The SEN0193 sensor exhibited correlation coefficients 0.76 and 0.73, respectively, for the Gyewol and Haechang sites, whereas the correlation of SMS-BTA and WT-1000B was not good enough for application in the field (Fig. 8).

There are some possible explanations for these errors in soil moisture content measurement. Site-specific calibration is necessary for accurate sensing; specific calibration was conducted for the sensor SEN0193 for the two plum farm soils. On the other hand, the two commercial sensors were calibrated at the manufacturing site and hence were not calibrated for specific plum farms. Therefore, it is recommended that each individual sensor should be uniquely calibrated for the soil and conditions in which they would operate (Varble and Chavez, 2011). During the calibration process, the effects of bulk density, temperature, and depth should be considered. Bulk density affected the readings of SEN0193, while temperature and sensor depth had no influence. Hence, the obtained data differs from farm to farm depending on the field conditions. Thus, it is thought that the best calibration procedure to use for each sensor is field-based calibration (Varble and Chavez, 2011) as done with the SEN0193 sensor. If calibration is done perfectly, cheap sensors can also provide sufficiently accurate reading.

Furthermore, some sensors failed during the winter season. The SMS-BTA sensor buried at a depth of about
15 cm experienced circuit problems several times in frozen soil. Although WT-1000B stopped working in frozen soil condition, SEN0193 operated perfectly in the same conditions.

The reason for the damage incurred by SMS-BTA during winter is as follows. The freezing of water in the capsulation cover for insulating the electric circuit caused the failure. On the other hand, the reason for the failure of WT-1000B is not clear. Nevertheless, freezing is assumed to be a major factor because the failure occurred in winter.

Long-term monitoring of soil and environment properties

The year-round field data collected from the sensors at the Gyewol and Haechang sites in Suncheon city (climate temperature, rainfall, soil temperature, soil moisture, and humidity) are shown in Figure 9 and 10. At the same time, information on all these parameters was collected from the Korea Meteorological Office website (KMA, 2018) for Woldeong-myun and Haeryong-myun in Suncheon city for comparison with the sensor data. In this context, it should be mentioned that the rainfall gauge was set on June 2018 and rainfall data was recorded from 25th June 2018.

In the graphs (Fig. 9 and 10), it can be observed that climate temperature, humidity, soil temperature, and rainfall varied depending on the weather (summer, winter, fall, and spring).

Climate temperature and humidity at the two sites

When climatic temperature was compared to website data at the two farms, the sensor readings were found to be almost similar with the website data. However, the DHT22 climate humidity readings were very different from the website data. The website data on climatic humidity was found to be lower in winter rather than in summer. This is possible because for a specific location, humidity can change depending on the total area. As a result, the climatic temperature and humidity information from the weather station should be referenced in some farming decisions.

When the two sites are compared, it is observed that the average air temperature of Haechang is 1.23°C.
Figure 9. Climate temperature and humidity during the observed period in the two plum farms. (a), (c) Gyewol farm and (b), (d) Haechang farm.

Figure 10. Soil temperatures for the observed period. (a) Gyewol farm and (b) Haechang farm. (c) Rainfall intensity with soil moisture in the Gyewol farm.
greater than that of Gyewol. In Gyewol, there were 10 days below “zero” degree while there were only 4 such days in Haechang, which means that the Haechang farm is warmer than the Gyewol farm.

**Soil temperature in two sites**

The soil temperature data of the two farms was compared with the website data. In the autumn and winter seasons, the temperature sensor readings were found to be similar with the website information. On the other hand, some differences were observed with website ground temperature to soil temperature sensor reading. The website data at the two sites was found to be higher in spring and summer seasons rather than in autumn and winter seasons. This difference can be attributed to the difference in the location of information collection. The DS18B20 soil temperature sensor was set at a depth of 10 cm, but the website data was obtained from the ground surface of the weather station, which is easily affected by changes in the air temperature.

When rainfall started in August (Fig. 10-a, 10-b), the soil and climate temperatures started to decrease. The average soil temperature of the Haechang site was observed to be 0.89°C greater than that of the Gyewol site. There were 20 days with a below “zero” degree temperature in Gyewol but no such days occurred in Haechang. This means that the Haechang farm is warmer than the Gyewol farm.

**Rainfall and soil moisture**

Soil moisture and rainfall information from the Gyewol farm was compared with the website rainfall data. In Figure 10-c, it can be seen that the soil moisture content in the farm varied with respect to precipitation. Rainfall occurred every day in August 2018, which resulted in an increase in the soil moisture content. Further, there were large differences between the website rainfall information and the rainfall gauge (TR-525M) readings. The website data was more frequent than the rainfall gauge readings. This might be because rainfall at a specific location can be lesser than that in a wider area. As a result, rainfall data at a specific site is more important than weather information from the website. From these results, it can be deduced that a rainfall gauge can be used to collect actual rainfall data at individual plum farms.

From the test results, various parameters like climate temperature, relative humidity, soil temperature, soil moisture and rainfall were able to be obtained within one device and were stored in web DB, which could be helpful for farmers to plum growth monitoring. In addition, field data from local farm monitoring systems could be used complementary with website weather information.

**Conclusion**

In this study, a plum farm monitoring system was developed and evaluated for monitoring the real time soil and environmental parameters in fields.

1) The major advantage of the DAQ system lies in the integration of a wireless sensor network, a database server, and a web server into one single compact credit card-sized computer (Raspberry Pi) with a simplified program, which can be easily configured to run without a monitor, keyboard, or mouse.

2) The effects of soil temperature, depth, and bulk density on the SEN0193 sensor were studied. The output reading increased with an increase in the bulk density, resulting in statistically significant differences (p < 0.05). Changes in the temperature and depth did not affect the SEN0193 soil moisture measurement data. Therefore, a linear calibration equation was developed by running laboratory tests on the plum farm soils.

3) The correlation coefficient of SEN0193 sensor between real value and reading value of soil moisture content shows 0.76 and 0.73 for the Gyewol and Haechang sites, respectively. The reading errors of two commercial sensors, SMS-BTA and WT-1000B, were 2.7 and 2.0 times higher, respectively, for the Gyewol site and 2.4 and 2.2 times higher, respectively, for the Haechang site, when compared to the reading errors of the SEN0193 sensor. The errors of the commercial sensors can be attributed to a lack of site-specific calibration. The SMS-BTA and WT-1000B sensors stopped working in frozen soil conditions, whereas the SEN0193 sensor operated perfectly in the same conditions.

4) The performance of the DS18B20, DHT22, and TR-525M sensors in the two plum farms was evaluated with specific farm website data. During long-term monitoring, the climatic temperature
values were found to be almost similar to the DHT22 temperature readings. It was also found that the average air temperature of the Haechang area is greater than that of the Gyewol area. There was a difference between the website climate humidity data and DHT22 humidity readings because specific farm humidity can vary depending on the total area of measurement.

5) A difference was found between the website ground temperature data and soil temperature sensor readings. This might be because the DS18B20 sensor was set at a depth of 10 cm. The website information on rainfall was more frequent than the rainfall gauge data. Therefore, rainfall data collection on site is important to monitor soil moisture in a specific environment. On the basis of the long-term monitoring data, it could be concluded that farm-specific temperature, humidity, and rainfall at any site would vary depending on the total area. Therefore, site-specific data is highly important for monitoring any fruit or crop.

Conflict of Interest

The authors have no conflicting financial or other interests.

Acknowledgement

This research was supported by the RDA (Rural Development Administration), Republic of Korea (PJ01 2292).

References


https://doi.org/10.5307/JBE.2017.42.4.283


https://doi.org/10.1016/j.jhydrol.2007.06.032


https://doi.org/10.1016/j.procs.2014.07.059


https://doi.org/10.1002/hyp.1358


http://doi.org/10.1016/j.agwat.2005.12.005


Shi, J., J. Gong, J. Liu, X. Wu and Y. Zhang. 2009 Antioxidant capacity of extract from edible flowers of Prunus mume in china and its active components. LWT - Food Science and Technology 42(2):477-482

https://doi.org/10.1016/j.lwt.2008.09.008


https://doi.org/10.1016/j.agwat.2011.09.007


Jeonju-Si, Jeollabuk-Do. Republic of Korea: Rural Development Administration.