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Investigation of Soil Wetting Pattern in Drip Irrigation using LoraWAN Technology

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ABSTRACT. ***Soil moisture based irrigation was used widely due to its low cost, effectiveness in saving water, and increasing of crop yield. However, soil moisture under drip irrigation varies spatially due to the influences of environmental factors. That means the location of soil moisture sensors can affect the soil moisture levels in a field. Thus, investigation of soil water movement to guide the placement of soil moisture sensors could be an important factor for well-designed soil moisture based irrigation system. To investigate the water movement under drip irrigation, an Internet of Things (IoT) system including soil water potential (SWP) sensors, LoRa (Long Range) communication system, local gateway, and cloud server was developed. 16 SWP sensors were placed in crop root zone at one side of an emitter along with the dripline. With the designed configuration, the data of SWP sensors could be monitored and accessed by end users through internet. The developed IoT system was tested and evaluated functionally, even there was no irrigation event during the period. The results indicated that The SWP sensors could detect the change of SWP and were sensitive enough to respond these changes during a precipitation event. The outcome from this study showed the effectiveness of the LoRaWAN based IoT system in the investigation of water movement in the soil. More experiment will be conducted to measure the soil water movement under drip irrigation in the future.***

Keywords. IoT, LoRaWAN, soil water potential, drip irrigation

1. Introduction

It is an urgent need to reduce water waste while maintaining the water and food security to the world's increasing population (Kamienski et al., 2019). A well-managed irrigation can develop maximum crop yield per unit of water applied to achieve desired ecological sustainability with a minimum of unavoidable losses (Oktem, 2008). Drip irrigation is a type of micro-irrigation system allowing water to drip slowly to plant root zone. The soil evaporation as well as deep percolation under drip irrigation are greatly reduced (Locascio and Smajstrla, 1996; Meshkat et al., 2000; Elmaloglou and Diamantopoulos, 2009). Besides, drip irrigation caused soil crusting due to the reduction of surface runoff (Hodgson et al., 1990). Therefore, drip irrigation system is a crop irrigation method with high water use efficiency that can help reserve water resources.

Conventionally, drip irrigation is mainly applied based on operator's experience or simple observation resulting in under-irrigation or over-irrigation. The improper timing and amount of water for irrigation can negatively affect crop quality, and waste of water and leaching of nutrients by over-irrigation (Sezen et al., 2006; Virág et al., 2020; Du et al., 2008; González Perea et al., 2018; Virág et al., 2020). Alternative methods are required for precision drip irrigation system. Evapotranspiration-based (ET-based) irrigation and soil moisture based irrigation are two available irrigation control technologies (Ko and Piccinni, 2009; Davis and Dukes, 2010; Irmak et al., 2012). ET-based irrigation uses reference ET (ET_0) which calculated by a set of climatic parameters including solar radiation, temperature, relative humidity, and wind speed to schedule irrigation (2000, Riley, 2005). The soil moisture based irrigation receives real-time feedback from soil moisture sensors which reflect the actual soil water status (Zotarelli et al., 2011). It is easy to maintain soil water status within upper and lower limits with using soil moisture based irrigation, which can prevent over irrigation, save water, and reduce cost (Dukes and Scholberg, 2005), leading to a wide application for modern irrigation systems.

However, soil moisture under drip irrigation varies spatially due to the influences of environmental factors (Dabach et al., 2016), such as soil hydraulic properties and their spatial heterogeneity, rooting patterns of crop, as well as irrigation system parameters (Elmaloglou and Soulis, 2013). Thus, the readings of soil moisture sensors can be different at different locations and measuring time. The data from soil moisture sensors used to guide the on and off of the irrigation is critical for a well-designed drip irrigation (Dursun and Özden, 2017). Soulis et al. (2015) found that soil water content sensors placement and accuracy may considerably affect irrigation efficiency. Accordingly, investigation of water movement in the soil can help for guiding the placement of soil moisture sensors. With accurate locations of these sensors, the data could be more representative to the soil moisture levels at the crop root zone.

On the other hand, it is critical to make decision for irrigation by receiving the data from soil moisture sensors in time. Wireless sensor network (WSN) is effective and convenient to connect soil moisture sensors in irrigation management, and has proved to achieve water savings (Munir et al., 2018). Some wireless technologies such as ZigBee, Bluetooth, GSM and LTE have been applied in irrigation system with some success on monitoring and controlling the irrigation events (Pavithra and Srinath, 2014; Yunseop and William, 2015; Chikankar et al., 2015; Khelifa et al., 2015). However, ZigBee and Bluetooth typically have a limited coverage, meanwhile, GSM and LTE have high power consumption and depend on the availability of mobile network (Usmonov and Gregoretti, 2018). These drawbacks make them difficult to be deployed in irrigation systems widely. LoRaWAN is a technology that provides long range communication with lower energy consumption and lower cost. It has already been used in irrigation system (Fraga-Lamas et al., 2020). For instance, Usmonov and Gregoretti (2018) presented a LoRaWAN based cost-effective wireless control system for drip irrigation, and found this method has the advantage of low cost and convenient for drip irrigation.

The main goals of this research was to investigate the characteristics of water movement under drip irrigation in an apple orchard using LoRaWAN based Internet of Things (IoT) system. Soil moisture sensors will be installed in orchard and a complete IoT of LoRaWAN will be developed to obtain the data of soil moisture sensors. The objectives of the study include:

1) Developing a LoRaWAN based IoT system for obtaining the data of soil moisture sensors in an apple orchard;

2) Investigating the principle of water movement in the soil under drip irrigation; and

3) Recommending rules for installing soil moisture sensors in the soil to accurately guiding irrigation events in a time manner.

2. Materials and Methods

2.1. Installation of soil water potential sensors

To achieve the proposed objectives, a series of experiments were conducted in a research orchard at Penn State Fruit Research and Extension Center (Biglerville, PA, 39°56' N, 77°15' W).A total of sixteen soil water potential (SWP) sensors (Watermark 200SS-5, Irrometer company, Inc., Riverside, CA) were used to detect the soil water distribution under drip irrigation. These sensors were evenly placed at one side of emitter along the drip line (Figure 1). There were four columns of sensors with four at each column. The closest sensor to the emitter was 0.1 m away both at lateral and underneath directions. The lateral distances of two neighboring sensors at the same depth were 0.1 m, and the vertical distances between two neighboring sensors in the same column was 0.2 m. The sensors were attached to polyvinyl chloride (PVC) tubing and placed in the soil at various depths. The value of SWP sensor gets to bigger numbers when the soil starts to lose water and becomes drier. These sensors were divided into four groups (the same column as a group) for recording data conveniently.

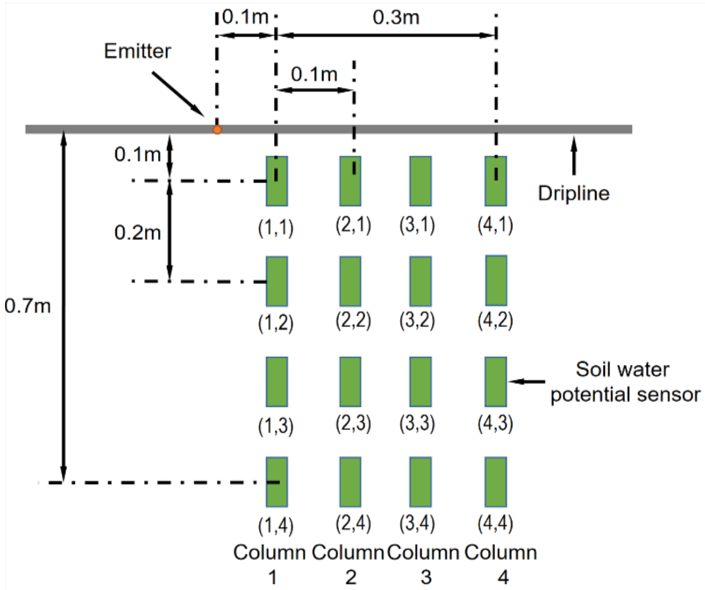

Figure 1. Distribution of soil potential sensors in soil.

A pre-installation procedure was applied according to the instruction. The SWP sensors were wet slowly by partially submerging them (no more than half way) in water for 30 minutes in the morning and let dry until evening, then continue for 30minutes and let them dry overnight before installation (Figure 2a). The sensors were cemented onto the pipe. A small hole was drilled at the bottom of PVC pipe to align with the slot at the top of the sensor housing. This allows any water that gets trapped in the pipe to drain away. Four SWP sensors were installed as a single assembly to make field installation easier (Figure 2b). The wires from the lower sensors were routed out a hole below the upper sensors and then routed back into the pipe through a hole above the sensor to keep all the wires contained inside the pipe sections where possible. The upper layer soil was removed because some stones existed, then four holes were drilled and the SWP sensors were placed in the holes (Figure 2c).

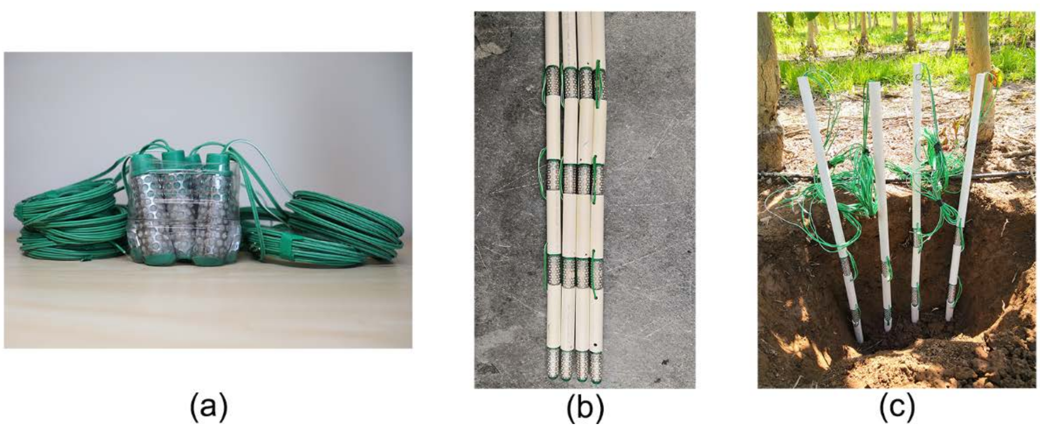

Figure 2. Installation of soil water potential sensors (a) submerging the sensors; (b) connecting the sensors with PVC pipe; (c) install sensors at different depths.

2.2. LoRa Hardware Platform for IoT system

An IoT system based on LoRaWAN technology was developed to monitor and record the data from the SWP sensors in orchard (Figure 3). Sensors were physically connected to the LoRa communication system. The sensor data was recorded by the LoRa system and then uploaded to the cloud sever through a local gateway wirelessly. Finally, the end users using computer or tablet can access the data from the cloud serve through internet.

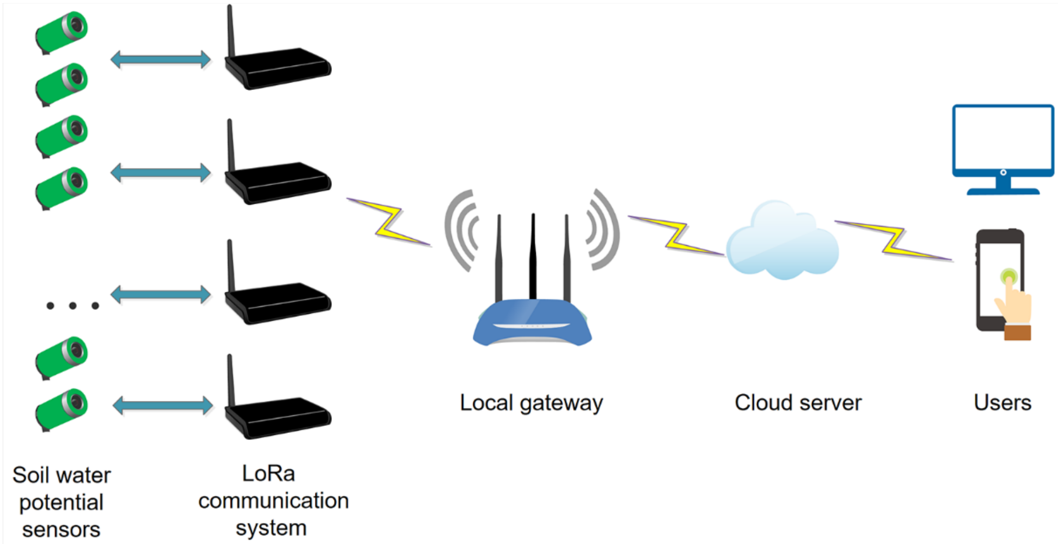

Figure 3. The structure of IoT system.

The LoRa communication system consist of a vinduino board (Vinduino LLC, Temecula, CA) and a dual-mode Compact RF Module with antenna (LM533H, GlobalSat WorldCom Corp., New Taipei City, Taiwan). The vinduino board is extended from an Arduino controller to connect all the sensors and execute the developed data acquiring algorithm (Figure 4a). The board is powered by a 3.7 V LiPo battery and a small solar panel. Each board can connect with four SWP sensors. The GlobalSat LM-533H is a LoRa based RF module that provides long-range (more than 10 km) and low data rate IoT connectivity (Figure 4b). A water-proof enclosure was used to house the vinduino board, GlobalSat LM-533H, LiPo battery and solar panel (Figure 4c). A RG150 gateway (Laird Connectivity Co. Ltd, Akron, America) was selected in this system (Figure 4d). It offers a LoRa range up to 10 miles and pre-loaded LoRa Packet Forwarder software, perfect for highly scalable, flexible IoT networks.

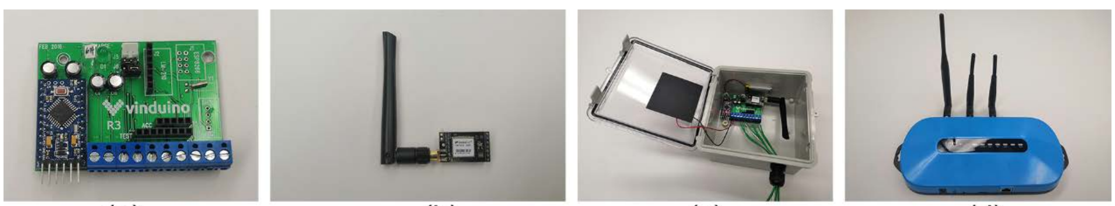

Figure 4. The devices used in IoT system, (a) vinduino board; (b) LoRa model; (c) the assembled LoRa communication system; (d) local gateway.

2.3. Communications Architecture for IoT system

One of the key components in IoT system is to create communications among the LoRa modules, gateway, cloud server, and users. Firstly, the gateway is connected to a router using Ethernet cable or configurate to a wireless network. There is an interface for configuring the gateway such as LoRa packet forwarder and frequency band. In our study, the gateway was set to connect with The Things Network (The Things Industries, Amsterdam, Netherlands).

An application was created for the experimental system through The Things Network. Four devices with unique end-device identifier (DevEUI) could be registered with The Things Network in the application. These devices represent the four LoraWAN modules used for connecting and recording soil moisture sensors. The LoRa communication modules are activated and exchange data with network server via over-the air activation. The DevEUI, the application identifier (AppEUI) were written in the join procedure, so the LoRa communication system can connect to server once the power is on.

The second step was to connect the configured Lora communications system to the IoT platform AllThingsTalk (AllThingsTalk NV, Mechelen, Belgium). The integration "AllThingsTalk" is added to the application in The Things Network. Then the AllThingsTalk was linked to the gateway server. Thus, the SWP sensors data was uploaded and stored in the AllThingsTalk platform. In the AllThingTalk platform, four devices which created in the The Things Network were added. In each device, five asserts were created which represent the corresponding data of SWP sensors and battery voltage. The communication was applied with a pre-set time interval, depending on the procedure in the LoRa communications system, which was 1 minutes in this research. The sensor data (uplink) was communicated as binary payload. The battery voltage and sensor reading was parsed from a byte between 0 - 255. They were converted to actual values by editing the payload format in the device interface. Thus, the data can monitor in computer and smart phone conveniently and timely.

3. Results and discussions

The developed IoT system was tested in the orchard, such as the feasibility of the system, and the recording of the sensors data. However, the soil water movement under drip irrigation were not available due to the extensive rainfall with no need for irrigation so far in the season.

3.1. Feasibility of the IoT system

In the test, the local gateway was located inside of the Fruit Research and Extension Center building, and the assembled LoRa communication systems were placed at the top of tree canopy to better receiving the signal from local gateway. The distance between the gateway and LoRa communication systems is about 450 m (Figure 5). The data of SWP sensors were successully uploaded to the cloud sever and monitored through a computer connected with internet. The LiPo battery with a solar panel was expected to power these LoRa communication systems for a whole growing season. However, two LoRa communication systems lost the signal after working 5 days and then worked normally after new LiPo battery was used. After investigation, we found that these batteries were not fully charged initially, and the solar panels were sheltered by leaves. By clearing the leaves around the solar panels would improve the charging capability to sustain these batteries in the future. Meanwhile, we did observe a few data loss during the period besides the power outage, which indicated the loss the communication connection between the gateway and the LoRa modules. It did not cause any issue since the loss is very limited, while it may be improved by rising the Lora modules into a higher location or moving the gateway outside of building.

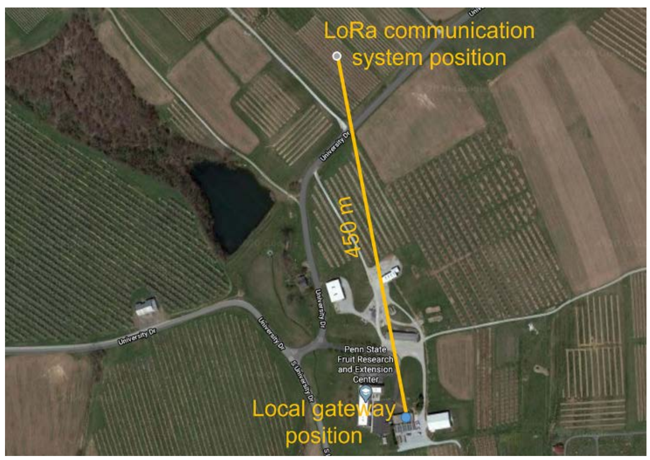

Figure 5. The locations of LoRa communication system and local gateway.

3.2. Soil moisture monitoring with IoT system

Figure 6 shows the SWP values measured by all SWP sensors from May 24th to June 5th. All the sensor readings followed similar trend. The SWP sensors were placed in the evening on 23rd May. The surrounding area were wetted by pouring some water to the soil to ensure better connection between soil and sensors. Thus, the values of these sensors were initially at small values on May 24th. After installation, the readings from these sensors increased gradually. For example, the sensors (1, 4) and (2, 4) which are at bottom in column 1 and column 2 recorded zero at the beginning. One exception was the sensor (4, 1) which had the initial reading of 19 kPa. There was no irrigation event applied during the period, while the results showed the change of soil water potential values at different locations according to the precipitation. After the precipitation, the reading from all sensors decreased obviously. Because the soil in bottom is hard to exchange water and air with atmosphere, the values of SWP sensors in bottom kept constant over the first few days and changed in the 4th days. In the column 3, the value of bottom SWP sensor (3, 1) had very big fluctuation around a large number. There maybe was some problems with the SWP sensor (3, 1) or the wires which connected the SWP sensor (3, 1) with LoRa communication system. Thus, the value of SWP sensor (3, 1) didn't presented in Figure 6.

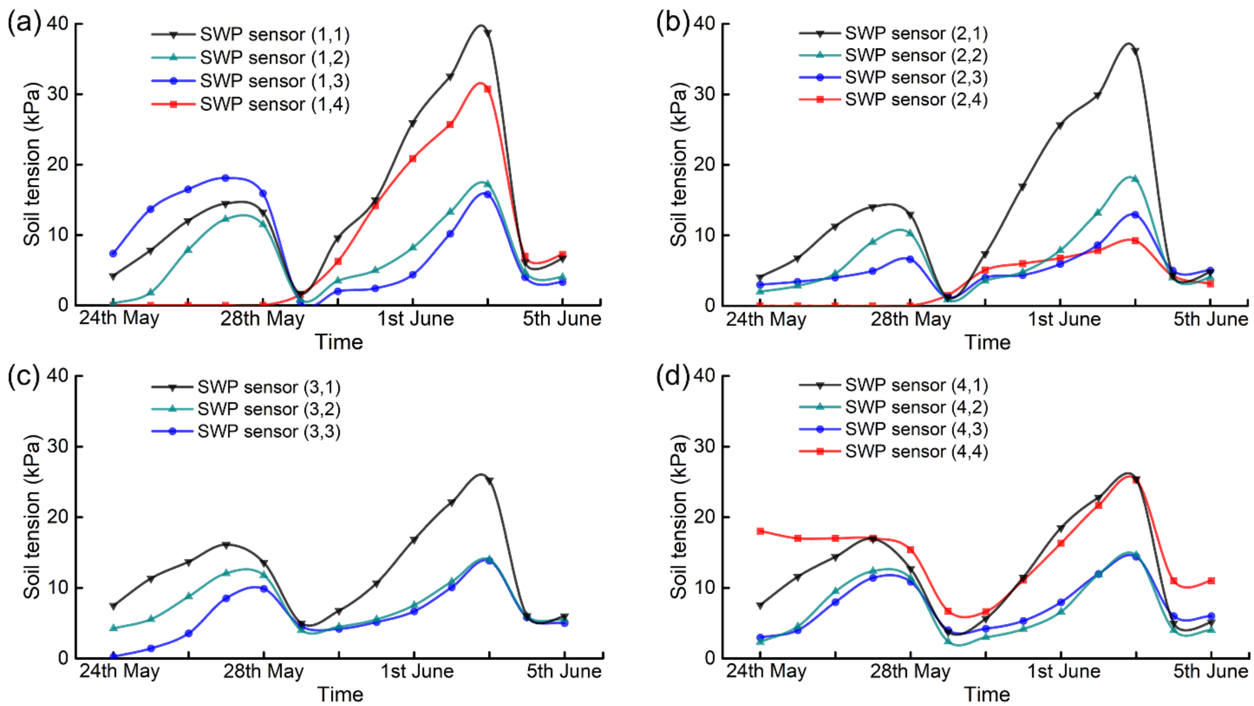

Figure 6. SWP monitored by sensors in (a) column 1, (b) column 2, (c) column 3, (d) column 4.

According to the weather data, there were 4.06 mm and 11.94 mm precipitation on the 28th May and 29th May, respectively (Figure 7). The readings of all sensors decreased on 28th May and 29th May because the soil became wet. Then these numbers increased gradually again. On 4th June, the readings of the SWP sensors decreased more rapidly than those on 28th May and 29th May due to lager precipitation of 22.92 mm. The results indicated that the SWP sensors were sensitive to the water movement and could respond quickly to the water status change. It also showed that the soil dried faster during the period of 29th May to 3rd June than the period from 24th May to 28th May.. From figure 7, we can see that the relative humidity was much higher at the time of 24th May to 28th than that from 29th May to 3rd June, which may be part of the reason to have more water evaporated from 29th May to 3rd June.

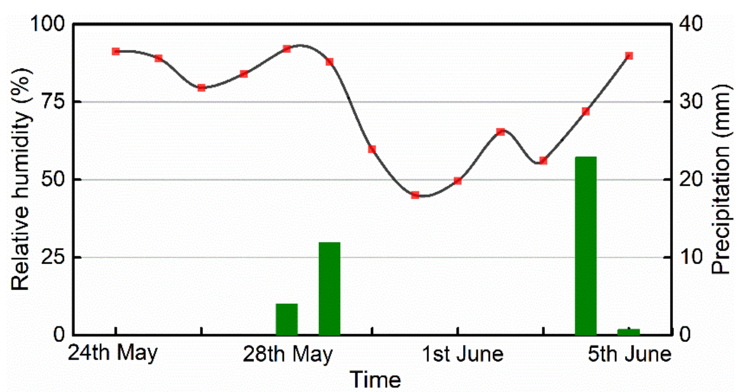

Figure 7. The relative humidity and precipitation in orchard.

For all four columns, the values of SWP sensors in the top layer had the largest number then followed by the SWP sensors in the bottom. This is due to the soil in the top lose water easier than the soil in deep (Klocke et al., 2009). The SWP sensors in bottom is difficult to get water with small precipitation.

The detailed changes of SWP during a precipitation event were also analyzed. The changing trend of SWP in 4 column could be similar because the water infiltrated evenly when rain occurred, so only SWP in column 1 was analyzed as an example. Figure 8 shows the SWP changing from 17:20 to 18:00 on 4th June. The rain started at 17:20. The reading of SWP sensor (1, 1) started to decrease firstly in10 minutes later. After about 30 minutes, the SWP sensor (1, 3) and (1, 4) decreased simultaneously even though these two SWP sensors were located at different depths. It was 20 minutes later for the readings of SWP sensors (1, 3) and (1, 4) to start decreasing comparing to the SWP sensor (1, 1). Ideally, the water moves gradually from the top to the bottom in the soil. While as shown in Figure 8, the second SWP sensor (1, 2) was the last one to change, which could attribute to the soil properties around the sensor, or errors associated with sensor installation. More investigation will be conducted to identify the possible issue in the future.

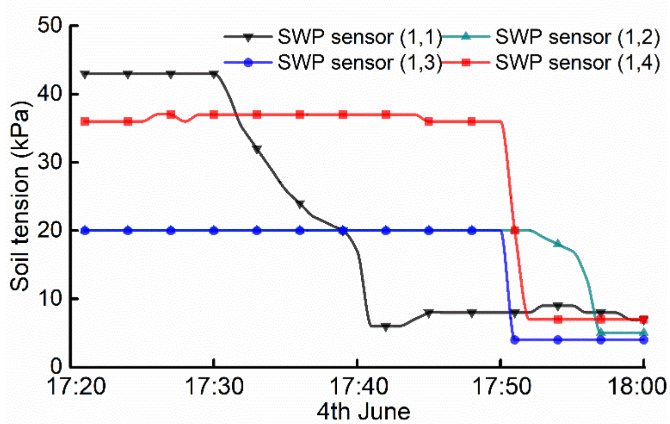

Figure 8. Detailed changes of SWP when rained on 4th June.

4. Conclusion

In order to investigate the characteristics of water movement under irrigation in an apple orchard. 16 SWP sensors were placed in the orchard and a LoRaWAN technology based IoT system was developed. Even though the irrigation event not scheduled yet, but some valuable results still analyzed via test the IoT system. The following specific conclusions can be drawn from this study.

1) The IoT system is effective to monitor the data from the SWP sensors with a long distance between local gateway and LoRa communication system;

2) The SWP sensors could detect the change of the SWP status in the soil during a precipitation event.

In summary, the IoT system based on LoRaWAN works normally and could be used to investigate the soil movement under drip irrigation. In the future, we will schedule some drip irrigation events to investigate the soil movement via this IoT system. Some improvements also will be carried out to enhance this experiment system such as replacing the SWP sensor which out of service and placing the solar panel in a better location.

Acknowledgments

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