



***Remote Sensing and GIS Applications For  
Agriculture and Precision Farming***

## ***Analysis of Environment and Physiological Data of Citrus Orchards by Using Field Server***

Masayuki Hirafuji, Hideo Yoichi, Yugo Miki,  
Hiroshisa Nesumi, Norihiro Hoshi, Tokihiro  
Fukatsu, Keiko Matsumoto  
National Agricultural Research Center  
National Agriculture and Food Research Organization  
Tsukuba, Japan  
{hirafuji, hyoichi, mikiyugo, nesumi, starnor, fukatsu,  
keikomatu}@affrc.go.jp

Kazuaki Nastuhara  
Graduate School of Life and Environmental Sciences  
University of Tsukuba  
Tsukuba, Japan  
kazuaki.nastuhara@gmail.com

**Abstract**— Soil moisture management based on the growth of citrus trees and environmental condition in orchards is the key to producing high-quality citrus fruits. Aiming for optimum irrigation management in citrus orchards, we have developed a Sensor Net–Farming System (SN-Farming System) by using Field Servers to monitor tree growth and environmental condition in orchards for a long term. The Field Servers are equipped with sensors, network camera, and wireless LAN module. By using the Field Server, we measured the moisture content of soil and tree, the temperature of air, soil, and tree stem, solar radiation, humidity, CO<sub>2</sub> concentration, and took pictures of citrus. As a result, we observed that: 1) the deeper the soil layer, the soil temperature become lower ; 2) the moisture content of tree stem and CO<sub>2</sub> concentration in tree showed a diurnal variation, being low in the daytime and recovering at night. These findings suggest the feasibility of Field Servers for optimum irrigation management of citrus orchards based on physiological and environment data.

**Keywords**—*high-quality citrus fruits; field server; soil moisture*

### I. INTRODUCTION

Satsuma mandarin citrus has a sweet and freshly sour taste, and its rate of consumption is high among fruits in Japan. However, the rate of consumption has declined because of an increase in imported fruits, diversity of consumers' tastes, and quality variation due to the weather, and the market price has remained stagnant. Due to this background, the citrus fruit-growing region in Japan rapidly decreased. To maintain and develop Satsuma mandarin-producing regions, the stable production of high-quality fruits meeting the tastes of consumers is necessary. To satisfy the tastes of consumers, an 11 Brix% or higher sugar content and about 0.7-1.0% acidity of fruit are considered desirable [1].

The following two cultivation techniques to produce high-quality fruits were developed. The first is the root-zone restriction culture of Satsuma mandarin trees [2]. This method increases the fine root density by restricting the root zone using a container or root-protective cloth. This treatment facilitates the absorption of soil nutrients and water

within a short time, avoiding an unnecessary late effect of fertilizers and promoting water stress, which increases the sugar content and quality of fruits. The second is the control of soil moisture, in which the soil is appropriately dried in a certain period to load water stress on trees [3]. It has been reported that it is favorable to initiate soil irrigation when the soil pF value reaches 2.0-2.7 and 3.0-3.8 in the fruit growth and ripening periods, respectively [4]. Loading water stress on trees is an important point regarding the above cultivation technique, but acidity reduction may be inhibited, depending on the timing and water stress level, while the sugar content increases.

To overcome this problem, precise water control based on both soil and trees condition is necessary. If environmental information, such as conditions for above-ground parts and soil moisture, and physiological information, such as the water condition of trees and photosynthesis rate, can be simultaneously obtained, precise water management can be performed, leading to high-quality fruit production. So, we have developed a 'Field Server' composed of multifunctional sensor nodes which performs the long-term fixed-point observation of an open field including agricultural fields, simultaneously measures various physiological and environmental data, and automatically collects the data via Internet [5-13].

The objective of this study was to simultaneously collect environmental data on citrus fruit farms and physiological data on citrus fruit trees using the Field Server and to analyze these data, aiming at optimum watering management to produce high-quality Satsuma mandarin fruits.

### II. MATERIALS AND METHODS

#### A. Experimental field

The experiment was conducted in the Tsurugamine Experimental Field (Zentsuji Senyu Town, Kagawa Prefecture, Japan) within the Kinki, Chugoku, and Shikoku Agriculture Research Center of the National Agriculture and Food Research Organization. In this field, *Citrus Unshiu* Marow 'MiyagawaWase' has been cultivated. MiyagawaWase is a representative species of early ripening *Citrus Unshiu*. The *Citrus Unshiu* trees now being cultivated

in this field have *Poncirus trifoliata* as their rootstock and are 12 years old. *Poncirus trifoliata* is highly resistant to cold and viruses. Because of these advantages, it is often used as a rootstock. *Citrus Unshiu* grown on *Poncirus trifoliata* has a relatively shallow root distribution, enabling easier drainage [14].

MiyagawaWase fruits can be harvested from the end of October to early December. Coloration of the fruit skin and the acid level serve as indicators of fruit maturation. A decrease in the acid level to 0.7-1.0% is considered to be an indicator of an appropriate time for harvest [1].

The soil covering this field is classified as brown forest soil. In Japan, brown forest soil is primarily used for farms (other than rice farms) and fruit gardens. The experimental field has been treated with manure whose base is weathered granite soil. It is known that if *Citrus Unshiu* is cultivated in granite soil, the branches and shoots will be shorter and the entire tree more compact, bearing high quality fruits [14].

### B. Field Server

We have developed a "Field Server," a compact-sized monitoring device capable of collecting diverse information simultaneously, including visual information on the fields and plants, physiological information on plants, and environmental information. Fig. 1 shows the external appearance of the Field Server. This device can conduct stationary observation for long periods of time in open fields. The data collected Field Servers are transferred automatically via the Internet. The data are integrated with the data grid (MetBroker, middleware for data grid) and made public on the Web [5-13].

Individual components of the Field Server are outlined below:

1) *Weather-resistant console*: As shown in Fig. 1, the console is made of poly-carbonate (a highly weather-resistant material) so that it may endure severe outdoor environments. It is a cylindrical form. It contains the parts listed in 2) through 7).

2) *Field Server Engine*: The Field Server Engine is a Web server displaying the collected data on the Web. It can be manipulated via a browser. The Field Server Agent automatically collects data from Field Servers installed in multiple places and processes the data into a database. The Field Server Agent periodically checks the Field Server installed in each place and conducts a series of tasks (data collection, turning ON/OFF the Field Server LED lamps, etc.) in accordance with a prescribed set of rules. The Field Server Engine is equipped with an A/D converter (24 bit/8ch, 10 bit/8ch), a D/A converter, a DDS (Direct Digital Synthesizer, MAX 70MHz), an FPAA (Field Programmable Analog Array), an analog multiplier, etc.

3) *Fan*: A fan is built into the Field Server for ventilation. This enables high precision measurement of the temperature and relative humidity with an Assman psychrometer, accompanied by cooling inside the Server.

4) *Power source*: Power is supplied from an outside source (DC12V) or a solar battery attached to the Field

Server. Long-term activation using a built-in solar battery is also possible if a timer circuit is used.

5) *Wireless LAN board*: IEEE802.11b/g access points are built in, forming Wi-Fi spots around the Server. Telecommunication at distances of up to about several hundred meters to three kilometers is possible depending on the antenna attached. If multi-step mediation with a meshwork or WDS (Wireless Distribution System) is applied, a multi-functional sensor network can be established, covering a wider area. Field Servers can thus make public the environmental information in plant producing areas as well as information on plant growth via the Internet.

6) *Network Camera*: Visual data have been utilized in the management and recording of plant cultivation, assessment of crop growth, distinction of plant diseases and pests, etc. Thus, visual information is very important at agricultural production sites. The acquisition of visual data with the network camera can be combined with the function of animal/plant monitoring and observation for the prevention of the theft of agricultural products, illegal disposal of waste in fields, etc.

7) *Sensors*: The following sensors were incorporated into the Field Server to collect environmental and physiological information needed for *Citrus Unshiu* management: (1) temperature sensor to measure the ambient and underground temperatures (3 underground layers with depths of 10, 40, and 70 cm; LM35, National Semiconductor), (2) humidity sensor to measure ambient humidity (CHS-GSS, TDK), (3) solar radiation sensor to measure the intensity of sunlight within the *Citrus Unshiu* farm (solar battery-driven), (4) soil moisture sensor and tree moisture sensor to measure moisture in the soil (3 underground layers with depths of 10, 40, and 70 cm) and tree (main stem 10 cm above the soil surface) (hand-made, details given later), and (5) CO<sub>2</sub> sensor to measure the carbon dioxide level in canopy and beside the *Citrus Unshiu* tree (CO<sub>2</sub>Engine™K30, SenseAir).



Figure 1. Field Server

The roots of *Citrus Unshiu* trees in this experimental field seemed to be spreading to a depth of about 40-50 cm underground. The soil moisture sensor, which checks for changes in electrical permittivity associated with soil moisture, was expected to facilitate measurement of the soil moisture in a broader area if the sensor size and electrode surface area were enlarged. For this reason, we installed two electrodes within the plastic pole (underground) of the Field Server and measured the capacitance between these two electrodes. The pole of the Field Server (1,000 mm in length, 100 mm in diameter) was divided into three equal portions; the upper, middle, and lower segments. In this way, we monitored soil moisture in three soil layers (depth: 10, 40, and 70 cm). The results from a preliminary experiment suggest that this sensor measures the weighted average of the soil moisture in the cylindrically shaped area (within 200 mm from the pole center and about 200 mm deep). A similar sensor for tree moisture measurement was also home-made to measure moisture at the main stem of the tree as shown in Fig. 1 (10 cm aboveground).

Two Field Servers began to be used in the experimental field in March 2010. Sampling with sensors was conducted for every 5 minutes.

### III. RESULTS AND DISCUSSION

#### A. Soil moisture

Fig. 2 shows an example of data on soil moisture. This graph pertains to measurement on April 3 through 6. In the future study, we will attempt to optimize soil moisture profile by regulating the irrigating devices depending on the tree growth state. From the viewpoint of linkage between irrigating devices and soil moisture sensors, relative values of soil moisture will suffice. For this reason, this graph show relative values of soil moisture (readings from the sensors) along the vertical axis. If prior calibration is performed, it is possible to calculate the physical level of soil moisture on the basis of the readings from the sensors used in this study.

It is noticeable from this graph that the soil moisture level was the highest at a depth of 70 cm (the deepest layer

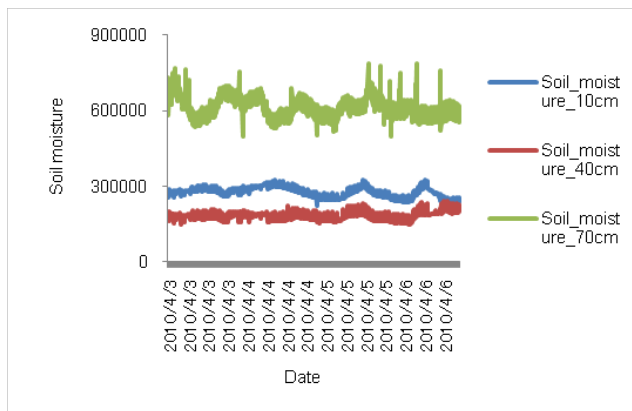


Figure 2. Soil moisture level

measured), second highest at 10 cm, and then at 40 cm.

When we conducted an on-the-site survey early in May, the corrosion of sensor cables and penetration of rain into the pole of Field Server were noted. These findings suggest that the sensors had been immersed in water, possibly making accurate measurement of the soil moisture impossible. At present, we are attempting measurement again after reinforcing the Field Server waterproofed.

Morimoto et al.[15] developed a neural network model for the prediction of fruit quality (sugar level and citric acid content) during the harvest season (November) based on chronological data on weather (rainfall and daily photoperiod, from August to November). Because the Field Server enables the continuous collection of information on the soil moisture, solar radiation level, and daily photoperiod (Fig. 5), it seems possible to utilize the soil moisture data or solar radiation level data in fruit quality prediction models like the one described above.

#### B. Tree moisture

Fig. 3 shows an example of data on the tree moisture level. Tree moisture was measured at the main stem of the tree as shown in Fig. 1 (10 cm aboveground). Like the graph shown in Fig. 2, the graph given in Fig. 3 pertains to measurement on April 3 through 6. The vertical axis corresponds to readings from the moisture sensors (relative value, same reason as soil moisture in Fig. 2).

It is noticeable from this graph that the tree moisture level showed a circadian variation, decreasing during the daytime and increasing at night. Considering that fine weather continued during the observation period, such a circadian variation seems to indicate that evaporation by leaves and water absorption by roots were normal.

#### C. Visual information

Fig. 4 shows an example of the images taken with the Field Server (taken on June 14). Usually, the above-ground parts of *Citrus Unshiu* trees grow in April and May. During this period, their spring branches (new shoots) grow and new leaves are formed. This picture shows dense leaf formation and juvenile fruits, indicating that the above-ground parts of the trees grew well in this field. The Field Server automatically yields visual information, enabling observation

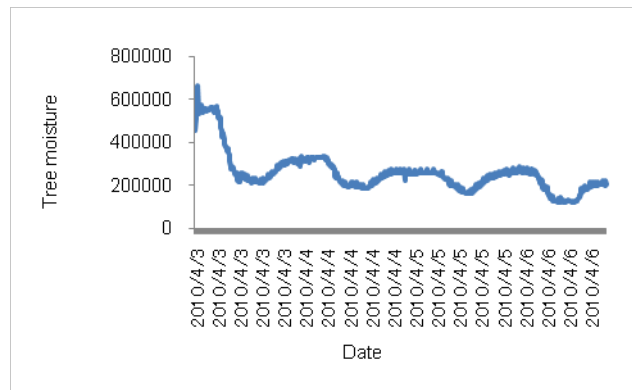


Figure 3. Tree moisture level



Figure 4. Image taken with the Field Server

over time of the leaf growth status, presence of June drop (a sign of tree activity reduction), status of fruit growth, etc.

It is known that the orange color of *Citrus Unshiu* fruit skin is primarily attributable to carotenoid. The amount of carotenoid increases during the course of sugar pooling in *Citrus Unshiu* fruits, and the fruit skin's orange color becomes deeper as the sugar level increases [14]. MiyagawaWase is harvested at the end of October to early December, and coloration of the fruit skin and the acid level serve as indicators of this fruit's maturation [1]. For this reason, information on the fruit skin color is indispensable for harvesting high-quality fruits at an optimal timing. Since the Field Server will continue to yield visual information from now on, it will be possible for us to assess the fruit color and growth status over time. These data are expected to be useful in judging the optimal timing of harvest.

#### D. Solar radiation and relative humidity

Fig. 5 shows an example of solar radiation level and relative humidity measurement data (data on June 24 through 30). The solar radiation level was evaluated on the output from the solar battery panel used as a sensor. It is noticeable from this graph that solar radiation levels on June 25 and 26 (both rainy days) were lower than those on the other days. This graph additionally shows that the solar radiation level varied in a 24-hour cycle, with a peak recorded around noon.

The relative humidity was 90% on the rainy days (June 25 and 26). On the other days, the tendency for the relative humidity to decrease during the daytime was reproduced well.

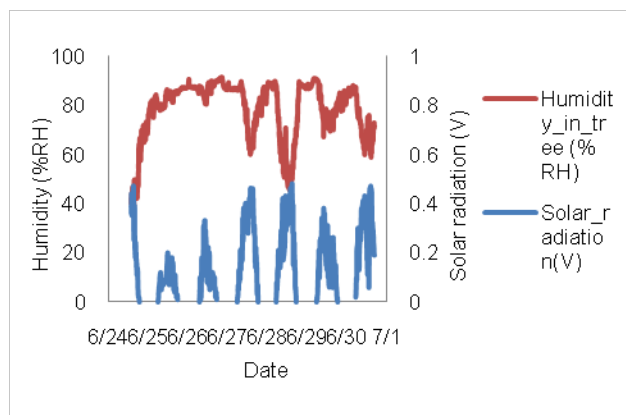


Figure 5. Solar radiation level and relative humidity

#### E. Air temperature

Fig. 6 shows an example of data from measurement of the air temperature, soil temperature (at depths of 10, 40, and 70 cm), and tree stem temperature (data on June 24 through 30). It was confirmed that the ambient temperature changes in a 24-hour cycle, with a peak recorded around noon. The mean ambient temperature during this period was 23°C. As shown in Fig. 4, the active growth of young leaves at a high density was confirmed by the visual information, suggesting that the ambient temperature recorded during this period was optimal for this plant.

It has been reported that the optimum temperature for sugar accumulation and translocation to fruits is about 18–20°C, and that the optimum temperature for the biosynthesis of carotenoid (involved in fruit skin coloration) is about 18°C [16]. It therefore seems that information on the ambient temperature in late August (the time when sugar accumulation in fruits begins to storage) has a crucial influence on the fruit quality during the harvest season.

In the present experiment, we confirmed that the continuous collection of ambient temperature data was possible for the March-June period. We will continue long-term monitoring of the ambient temperature and visual information until the late phase of fruit maturation, and will analyze the relationship between this information and the quality of fruits.

#### F. Soil temperature

Fig. 6 shows data on the soil temperature. The roots of *Citrus Unshiu* trees can be divided into thick and fine roots. Thick roots serve as the storage site of assimilates (formed in the leaves) during winter. Fine roots, on the other hand, are involved in the absorption of fertilizers and water and additionally serve as a site for storing excessive nutrients and water. In June, the underground parts (fine roots) grow [1]. Fine roots are located at the periphery of the main roots of *Citrus Unshiu* trees. Of the total fine roots, 70–80% is distributed in soil layers 30–40 cm below the surface. The entire roots are distributed in soil layers with a depth of up to 60 cm [4]. Therefore, monitoring environmental information reflecting the soil status in this range seems to be essential to improve the efficiency of fertilization.

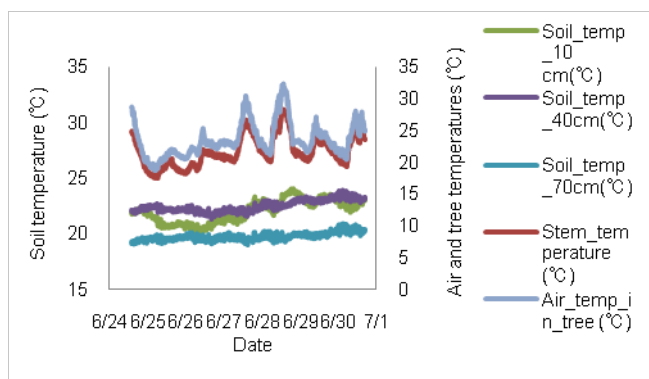


Figure 6. Air temperature, soil temperature, and tree stem temperature

In the present experiment, the soil temperature at three depths (10, 40, and 70 cm from the ground surface) was measured as environmental information for the underground part of *Citrus Unshiu* trees. As shown in Fig. 6, the soil temperature decreased as the soil depth increased. The mean soil temperature was 22°C at 10 and 40 cm and 20°C at 70 cm. The soil temperature range optimal for fertilizer absorption has been reported to be 20-28°C [14], and the soil temperature measured at each depth was within this range in the present experiment. The experimental field was fertilized with compost. In view of the report that the percentage of added organic materials converted into inorganic materials becomes higher as the soil temperature and pH rise (in the range up to 33°C and pH 7) [17], it seems to expect high rates of fertilizer absorption by *Citrus Unshiu* trees under the current conditions.

If the soil temperature becomes too low during winter (e.g., below 13°C), it is known that the absorbing potential of roots decreases and the water-absorbing resistance becomes extremely high, resulting in the suppression of nutrient and water absorption and growth of the above-ground parts, leading to low-temperature-induced damage. If the soil temperature becomes too high during summer (e.g., over 30°C), absorption through roots increases and the consumption of assimilates is intensified, accompanied by a reduction in fertilizer-absorbing potentials, necessitating regulation of the soil temperature by means of mulching, etc. [14]. For example, mulching protected the roots of *Citrus Unshiu*, *Brassica rapa* var. *nipposinica*, etc., from damage caused by high temperatures during summer, resulting in the favorable growth of these crops [18]. On the basis of these findings, we may say that soil temperature monitoring throughout the year is important in estimating the root activity and effects of manure and in ensuring the growth of *Citrus Unshiu* trees suitable for the given environments. We will continue soil temperature monitoring throughout the year and analyze the relationship between the growth of *Citrus Unshiu* trees and soil temperature.

#### G. Stem temperature

Fig. 6 shows data on the stem temperature. The data pertain to the surface temperature of the main stem (about 10 cm above the ground) of a *Citrus Unshiu* tree. The mean stem temperature was 22°C. The stem temperature followed the ambient temperature and showed a circadian variation. The stem temperature remained 2-3°C lower than the ambient temperature, suggesting the influence of solar radiation blocking by the densely grown leaves, absorption of underground nutrients and water, etc.

Generally, trees during active growth show marked evaporation, copious tree sap flow, and have a large stem. These trees are less susceptible to the influence of ambient temperature. Poorly growing trees are known to show features opposite to active growing trees. For example, it has been reported that the difference between the temperature inside the stem and that on the stem surface is useful in assessing the growth status of *Ginkgo biloba* [19]. In the case of *Zelkova serrata*, it has been shown that the difference

between the stem surface temperature and ambient temperature corresponds to the amount of tree sap flow, suggesting that the stem-ambient temperature gradient can serve as an indicator of the tree's growth potential [20]. These previous studies indicate the possibility of utilizing the tree stem temperature as an indicator of the physiological activity of trees. In the present experiment, we confirmed that the use of the Field Server facilitates the continuous and stable measurement of the ambient and tree stem surface temperatures. From now on, we will examine whether or not this information can be utilized to provide indicators of the growth potential of *Citrus Unshiu* trees.

#### H. CO<sub>2</sub> concentration in canopy and beside the tree

Fig. 7 shows an example of the data on CO<sub>2</sub> concentration in canopy and beside the tree. Like the graph shown in Fig. 6, the graph in Fig. 7 pertains to measurement on June 24 through 30. The CO<sub>2</sub> concentration in canopy labeled as CO<sub>2</sub> in tree in this graph averaged 450 ppm, depicting a pattern of diurnal change showing a peak at night. This suggests that photosynthesis in the daytime and respiration at night were normal. CO<sub>2</sub> concentration in canopy was almost constant on June 25 and 26 (both rainy days), photosynthesis seemed to be inactive. Since the experimental field is surrounded by buildings, the CO<sub>2</sub> concentration beside the tree labeled as the CO<sub>2</sub> in FS in this graph averaged 720 ppm, which seems to be very high in comparison to the ordinary ambient air CO<sub>2</sub> concentration (about 360 ppm).

In the case of long term measurement in open field, manual sensor calibration is often difficult. Though raw data is sensitive to back ground noise that inflates the mean value, normalized data is robust and useful to analyze the fluctuation pattern. Fig. 8 shows normalized data. Row data divided by mean value is normalized value. Normalized CO<sub>2</sub> concentration in canopy labeled as normalized CO<sub>2</sub> in tree increased in Fig. 8 increased moderately in daytime compared to normalized CO<sub>2</sub> concentration beside tree labeled as normalized CO<sub>2</sub> in FS. It is thought that photosynthetic activity in day time affected this phenomenon especially on June 28 and 29.

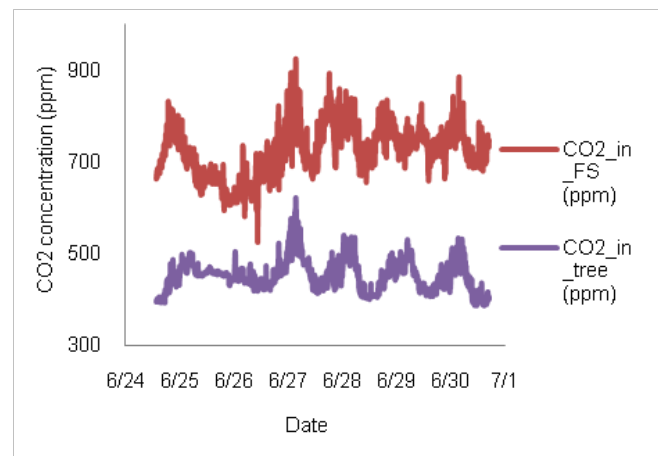


Figure 7. CO<sub>2</sub> concentration in canopy and beside the tree

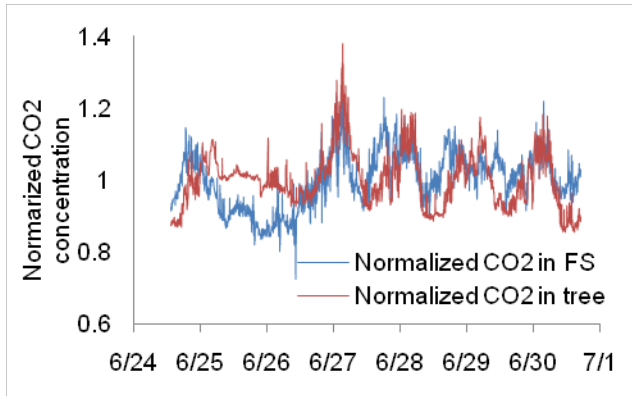


Figure 8. Normalized CO<sub>2</sub> concentration in canopy and beside the tree crown

Field Server that monitors tree growth and environmental condition for a long term and transfers collected data via Internet as stated above, enable to build a sensor network in open fields. Field Server with irrigation equipment will allow precision soil moisture management based on the growth of citrus trees and environmental condition in orchards. This field management, that is Sensor Net–Farming System (SN-Farming System), will produce high quality fruits. SN-Farming System that involves Field Servers will also facilitate to have diverse information in common via Internet and to refine conventional agricultural management practice.

#### IV. CONCLUSION

Soil moisture management based on the growth of citrus trees and environmental condition in orchards is the key to producing high-quality citrus fruits. Aiming for optimum irrigation management in citrus orchards, we have developed a Sensor Net–Farming System (SN-Farming System) by using Field Servers to monitor tree growth and environmental condition in orchards for a long term. The Field Servers are equipped with sensors, network camera, and wireless LAN module. By using Field Servers, we measured the moisture content of soil and tree, the temperature of air, soil, and tree stem, solar radiation, humidity, CO<sub>2</sub> concentration, and took pictures of citrus. As a result, we observed that: 1) the deeper the soil layer, the soil temperature become lower ; 2) the moisture content of tree stem and CO<sub>2</sub> concentration in tree showed a diurnal variation, being low in the daytime and recovering at night. These findings suggest the feasibility of this Field Servers for optimum irrigation management of citrus orchards based on physiological and environment data.

#### REFERENCES

[1] H. Nesumi, Citrus fruits (in Japanese), 9th ed., Tokyo: Japan Broadcast Publishing 2008, pp. 33-114.

[2] N. Okada, “Root-zone restriction culture of Satuma mandarin for high quality fruit production (in Japanese),” *Jpn. J. Soil. Sci. Plant. Nutr.*, vol. 65, no. 2, pp. 206-214. 1994.

[3] K. Morinaga et al., “Effect of drip irrigation and liquid fertilization system with year round plastic mulching on fruit production of Satuma mandarin (in Japanese),” *Hort. Res.(Japan)*, vol. 3, no. 1, pp. 33-37. 2004.

[4] H. Muramatu, *Physiology and cultivation of mandarin (in Japanese)*, 11th ed., Tokyo: Rural Culture Association Japan, 1978, pp. 1-221.

[5] T. Fukatsu, and M. Hirafuji, “The agent system for field monitoring sersders to construct smart sensor - network ” *Proc. of Fifth International Workshop on Artificial Intelligence in Agriculture*, pp. 1-5. 2004.

[6] T. Fukatsu, and M. Hirafuji, “Long-term monitoring system using field monitoring servers,” *Proc. of AFITA/WCCA Joint Congress on IT in Agriculture*, pp. 685-691. 2004.

[7] T. Fukatsu, and M. Hirafuji, “Field monitoring using sensor nodes with a web server,” *Journal of Robotics and Mechatronics*, vol. 17, no. 2, pp. 164-172, April. 2005.

[8] T. Fukatsu, M. Hirafuji, and T. Kiura, “A distributed agent system for managing a web based sensor network with field servers,” *Proc. of 4th World Congress on Computers in Agriculture*, pp. 223-228, July. 2006.

[9] T. Fukatsu, M. Hirafuji, and T. Kiura, “An agent system for operating web-based sensor nodes via the internet,” *Journal of Robotics and Mechatronics*, vol. 18, no. 2, pp. 186-194, April. 2006.

[10] T. Fukatsu, M. Hirafuji, and T. Kiura, “Consturction of support tools to assist an agent sistem,” *Proc. of AFITA/WCCA 2008*, pp. 221-227. 2008.

[11] M. Hirafuji, and T. Fukatsu, “Architecture of field monitoring servers,” *Proc.of the Third Asian Conference for Information Technology in Agriculture*, pp. 405-409. 2002.

[12] M. Hirafuji, T. Fukatsu, and H. Haming, “Full-Wireless field monitoring server for advanced sensor network,” *Proc. of AFITA/WCCA Joint Congress on IT in Agriculture* pp. 692-697, Aug. 2004.

[13] M. Hirafuji et al., “Sensor network architecture based on web and agent for long-term sustainable observation in open fields,” *Proc. of 12th International Conferance on Principles of Practice in Multi Agent Systems*, December. 2009.

[14] H. Muramatsu, *Basics of cultivation of Satuma Mandarin (in Japanese)*, 1st ed., Tokyo: Rural Culture Association Japan, 1982, pp. 208-212.

[15] T. Morimoto, Y. Ouchi, and M. Yoshinouchi, “A neural-network model for predicting the quality of 'Satuma' mandarin (in Japanese),” *J.SHITA*, vol. 17, no. 2, pp. 90-98. 2005.

[16] A. Kurihara, “Fruits Growth of Satuma Orange under Contralled Conditions. Effects of Diurnal Fluctuation in Air Temperature during the Fall on the Enlargement, color Development and Quality of Fruit,” *J. Japan. Soc. Hort. Sci.*, vol. 42, no. 1, pp. 13-21. 1973.

[17] K. Kondo, S. Matsui, and S. Ogata, “Relationship between N, P, and S availability for african millet and mineralization of add organic matter in granite regosols ( in Japanese),” *Jpn. J. Soil. Sci. Plant. Nutr.*, vol. 63, pp. 1-9. 1992.

[18] K. Kondo et al., “Effect of recycled paper mulch on the growth, ascorbic acid content, and nitrate concentration of Mizuna (*Brassica rapa L. japonica* group) under high temperature conditions (in Japanese),” *J.SHITA*, vol. 22, no. 1, pp. 15-21. 2010.

[19] A. Yabuki, K. Yoshikawa, S. Hasegawa, and T. Kozawa, “Influence of thermal environment around tree to stem temperature (in Japanese),” *J.Jpn. Soc. Reveget. Tech.*, vol. 27, no. 1, pp. 300-303. 2001.

[20] T. Oota, T. Tange, S. Sasaki, Y. Matsumoto, and T. Kozawa, “Studies on an evaluation method of the plant activity (in Japanese),” *J.Jpn. Soc. Reveget. Tech.*, vol. 17, no. 2, pp. 18-24. 1992.