SUSTAINABLE IRRIGATION USING INTERNET OF THINGS

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Abstract
Water is one of the most essential natural resources, which plays an important role in agriculture. The ever-increasing shortage of water and the continuous deterioration of its quality are evident in many countries of the world. The rational use of water in irrigation can be achieved by adopting scientific irrigation scheduling. Today, the traditional irrigation systems should be transformed to smart-irrigation systems for sustainable water management. This highlights the importance of adopting a set of emerging technologies that promise minimising implications of water scarcity. An Internet of Things (IoT) system uses various enabling technologies, such as wireless sensor networks, cloud computing, big data, embedded systems, security protocols and architectures, communication protocols, and web services. In this paper is presented an IoT-based precision irrigation technology using wireless sensor network (WSN). The system was installed in hemp plots to monitor soil moisture and satellite images were analyzed to understand the impact of soil moisture on hemp canopy. The results showed that the soil moisture variability remained the same at each plot during the one-year experiment while canopy properties depended on other factors that will be studied next year. This emerging technology is promising to improve irrigation water use efficiency.

Key words: *irrigation scheduling; capacitance sensor; wireless technology.*

INTRODUCTION

Water is one of the most essential diminishing natural resources. Farming is the dominant water consumer because it uses the 70% of the available fresh water. The ever-increasing shortage of water and the continuous deterioration of its quality are evident in many countries of the world. Especially in Greece, where the largest consumer of available water resources is irrigated agriculture (70%), water demand is significant in the summer, when water availability decreases to meet irrigation needs. In Greece, the quantities of water per irrigated area of 1000 m^2 amount to an average of 376 m^3. The higher quantity is used by southern Greece, where the number reaches 576 m^3. In contrast, northern Greece uses smaller amounts of water per 1000 m^2, such as 248 m^3. Irrigation in Greece is still applied by farmers after soil and plant observation without using scientific documentation and guidance resulting in the waste of water resources. Over-irrigation usually does not have a direct effect on the crops, thus farmers tend to "feel safe" by increasing irrigation above the real plant needs, especially when the price of irrigation water is too low. It is estimated that of the irrigation water applied, only 65% is used from crops, while 8% is lost during transport, 7% during its application in the field and 20% is lost due to over-irrigation (*Chartzoulakis & Bertaki, 2015*).

The rational use of water in irrigation can be achieved by adopting scientific irrigation scheduling (also known as irrigation water management). For this reason, it is necessary to calculate the irrigation needs as accurate as possible, using data from agro-meteorological station located in the near area. In addition, it is necessary to utilize sensors to monitor soil moisture in fields. Therefore, irrigation management is considered a vital component in agriculture, both for the environmental protection and for the stability of agricultural income.

Nowadays, the traditional irrigation systems transforms to smart-irrigation systems for sustainable water management. This highlights the importance of adopting a set of emerging technologies - such as Internet of Things (IoT) and precision irrigation models and controls - that promise minimizing implications of water scarcity. IoT refers to a system in which applications and services are driven by data collected from spatially planned and distributed remote sensing devices that sense and interface with the physical world. A typical IoT system architecture is based on three layers: a) device layer, b) gateway layer, and

c) platform layer. The device layer of IoT comprises of sensors and actuators for sensing and actuating the physical environmental conditions. The gateway layer is considered as the various communication protocols or computing devices that bridge the connection between the things layer and IoT platform layer. The IoT platform layer is a suite of cloud-based and/or on premise software components which facilitates data communication, flow, device management, and application support and management (*Sheng et al., 2017; Boursianis et al., 2020*).
An IoT system uses various enabling technologies, such as wireless sensor networks, cloud computing, big data, embedded systems, security protocols and architectures, communication protocols, and web services (*Sheng et al., 2017; Boursianis et al., 2020*). A wireless sensor network (WSN) is a group of spatially distributed smart sensors for monitoring, and recording the environmental conditions (such as soil water content; swc), storing the collected data, and transmitting the gathered information at a central station (*Liakos et al., 2017*). The main building block of the wireless sensor network is the sensor node. The main components of a sensor node are a microcontroller, transceiver, external memory, and power source. WSN is an important tool that is used in numerous applications such as to perform precision irrigation, providing farmers with a detailed knowledge of the amount of water exists in the soil at relatively low cost (*Delin, 2002; Liakos et al., 2017*).
The objectives of this study are a) to present an IoT-based precision irrigation technology using wireless sensor network (WSN), b) to show how this technology can help farmers to improve irrigation water use efficiency and c) to study if soil moisture plays an important role on canopy properties.

MATERIALS AND METHODS

The study was conducted in six experimental plots located in the Department of Agrotechnology - University of Thessaly, Larissa, Greece (39°37′34.0″ N, 22°22′52.8″ E, elevation of 80 m above sea level). The size of each plot was 7m x 8m.
Before the establishment of the crop, a soil sampling took place in the experimental site. Soil samples were taken from each plot at a depth of 0.3 m. The soil samples were then mixed to form a single composite soil sample, as representative as possible. The modified Bouyoucos method was used to determine the soil mechanical composition (*Gee and Bauder, 1986*), while the field capacity (FC) and permanent wilting point (PWP) of the soil were determined according to *Klute (1986)*. According to the above method, the soil texture of the plots is categorized as sandy clay loam (SCL). Further information for the particles size distribution and soil physical characteristics of the plots are presented in Table 1.

Tab. 1 Particles size distribution and soil physical characteristics of the plots

Properties		Depth 0 – 0.3 m
Particles size distribution	Sand	65 %
	Silt	10 %
	Clay	25 %
Soil physical characteristics	Dry bulk density	1.3 g/cm^3
	Field capacity	28 %
	Permanent wilting point	14 %

To develop a desirable soil structure suitable for seedbed, plowing with a depth of 25 cm was carried out, followed by secondary tillage with a rotary tiller at depth of 15 cm. A hemp crop (Cannabis sativa L.) was established on May 5, 2020 at the plots. The variety used for the experiment was Futura 75 and it was selected based on climate adaptation requirements and on seed and fiber yields potentials. Hemp plants were established in a row distance of 30 cm and plant distance of 3 cm.
Irrigation of hemp is one of the most important factors in crop yield and quality (*Tang et al., 2017a*). A drip irrigation system was installed in the experimental site. It consisted of hardware (electrovalves, filters, pressure gauges etc.) and the driplines with connection fittings. The PE lateral lines were placed between the sowing rows, at a distance of 1.2 m. Each lateral line had in-line emitters which the discharge rate was 3.6 L/h. The spacing between emitters was chosen as 1 m. During the growing season, irrigation was applied in total 487 mm.

The implementation of the Internet of Things (IoT) and wireless sensors (WS) in the proposed remote soil moisture monitoring and logging system consists of several parts as shown in Fig. 1. Wireless sensors which are distributed on the experimental site collect field sensing data, process and communicate over wireless channel with the Internet. End user (farmer) can monitor soil moisture and weather station data by browsing the cloud web server. In addition, the IoT based soil moisture monitoring and logging system includes databases, information files and a friendly graphical user interfaces (GUI) for computers and mobile devices.

The WS are an ecosystem of soil moisture sensors and a weather station placed in the experimental site. Air temperature, relative humidity, barometric pressure, rainfall, wind speed, wind direction, and solar radiation are standard measurements taken by the nearest weather station. Sensor nodes were developed by the Agricultural and Environmental Solutions (AGENSO), Athens, Greece. Each sensor node plays the role of a base station that transmitting its information through the Internet to cloud server. A node can support one soil moisture sensor, a weather station, and an external power unit (solar cell). The architecture for such node comprises of analog sensor channels, onboard digital signal processor (DSP), RAM and flash memory, GSM modem, global navigation satellite system (GNSS) receiver, LCD display, and power source. The hardware components are enclosed in an IP68 box, to protect them from damages and environmental conditions. These sensor nodes were developed to be power efficient and run by one rechargeable battery for a long period of time, since the whole system enters in deep sleep mode after collecting and transmitting the sensor information to save energy (*Tsiropoulos et al., 2022*).

The measurements of volumetric water content (VWC) are essential for assessing the status of hemp crop available moisture in soil. Thus, six low-cost sensors (ECH$_2$O probe model EC-5) were utilized to measure the volumetric swc under natural conditions in each plot. One sensor was installed in each plot horizontally in a depth of 25 cm from the surface. The EC-5 was selected because it is much less sensitive to variation in texture and electrical conductivity as it runs at a frequency of 70 MHz. The EC-5 sensor had dimensions 8.9 x 1.8 x 0.7 cm. It determines VWC by measuring the dielectric constant of the soil using capacitance/frequency domain method.

Several researchers (*Iwata et al., 2017; Dong et al., 2020*) reported that the performance of the factory-based calibrated EC5 sensors have shown overestimate or underestimate the soil moisture, depending on the characteristics of the soil. Thus, sensors should be calibrated for specific types of soil in order to improve their accuracy. The manufacturer has provided different calibration equations to describe the relationships between the output and VWC for the EC-5 sensor. This relationship (for non-METER data logger) is often linear as shown below:

$$\theta = (11.9\text{x}10^{-4})(mV) - 0.401 \tag{1}$$

where θ is the volumetric water content, mV is the output of the EC-5 sensor when excited at 2.5 V. According to manufacturer this equation reaches a maximum at ~60% VWC in pure water. To display data on a scale from 0% to 100%, VWC should be modeled with a quadratic equation (which would result in a 100% VWC in water), but a linear equation fits the mineral soil VWC range as well as the quadratic, and linear equations are easier to deal with, especially since mineral soil typically saturates at ~40% to 50% VWC.

Ardeusi.gr web interface is graphical user interface (GUI) for farmers use. The user component includes a task/query management component that collaborates with task management on sensor node, forming a channel for information and control flow between the sensor node and the GUI. By this way the GUI provides the ability to send tasks or queries to a sensor node and to display the following results: soil moisture data, weather data (e.g. air temperature, relative humidity, barometric pressure, rainfall, wind speed, wind direction, etc.), soil water reservoir thresholds (field capacity - FC, permanent wilting point - PWP, maximum allowable depletion- MAD) and charge battery. Soil moisture and weather data updates displayed as soon as they become available at the workstation and in the time sequence in which the measurements occurred.

Fig. 1 The wireless sensors (WS) placed in the experimental site

Sentinel 2 satellite images were analyzed for the 2020 growing season as far as the Normalized Difference Vegetation Index (NDVI) and the Normalized Difference Water Index (NDWI). Additionally, swc maps created based on the data collected from sensors and descriptive statistics for swc were estimated utilizing the SPSS 16.

RESULTS AND DISCUSSION

The descriptive statistics of swc are presented at table 2. It is worth mentioning that data follows normal distribution because skewness is higher than -1 and less than 1. Additionally, the mean swc is almost equal to median, which means that the bell curve of the dataset is symmetrical. The fact that the kurtosis is less than three means that there are no extreme high or low values (outliers). Moreover, the soil moisture values did not varied too much thus the coefficient of variation is low (0.14).

Tab 2. Descriptive statistics of swc during the 2020 growing season

Property	Value
Min	42.4
Max	74.4
Mean	59.6
Median	59.9
Standard deviation	8.5
Variance	72.3
Skewness	-0.4
Kurtosis	-0.2
Coefficient of variation	0.14

Figure 2 presents the average values of NDVI and NDWI for each plot during the 2020 growing season. According to it, the NDVI was lower at the northwest plot and higher at the south west plot while the NDVI values at the rest plots was almost the same. On the other hand the NDWI was higher at the northwest and southeast plots and lower at southern central plot. At the rest plots the NDWI value was the same. Variability between NDVI and NDWI map has already mentioned at the literature (*Hussain et al. 2019*).

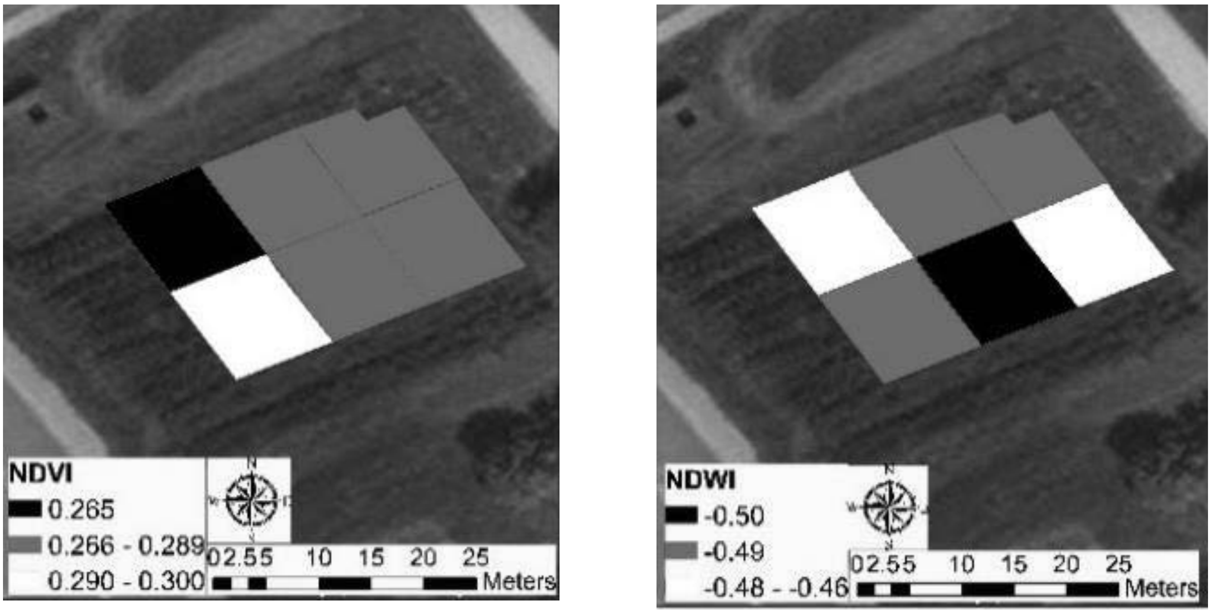

Fig. 2 Right: Normalized Difference Vegetation Index (NDVI) map, Left: Normalized Difference Water Index (NDWI) map. Both maps uses all the data from the 2020 growing season. The darker the colour the lower the value and the opposite

Figure 3 shows the monthly spatial variability of the swc as it was recorded by the installed soil moisture sensors. The color of each plot is given based on the average swc during the 2020 growing season. Surprisingly, the swc variability was the same every month and the only noticeable changes are the values of swc. In overal, the plots at the east side of the site had higher average swc than the plots at the western side. Thus, it is clear that the spatial variability of the soil water content is high even if the plots are close to each other and the total area is small (*Liang et al. 2016*). This explains why yield variation is high even in small fields (*Gemtos et al., 2005*).

The comparison of the swc maps with the NDVI and NDWI maps does not reveal specific patterns or any correlation among them. This means that there are other factors than irrigation that affect the vigour of the plants (NDVI) and the leaf moisture (NDWI). On the other hand, the fact that the average monthly swc variability was the same every month demonstrates that soil variability is high even in small areas and promotes the importance of utilizing a system to monitor soil moisture and the necessity of using Variable Rate Irrigation systems to manage this variability increasing the farmers' profit.

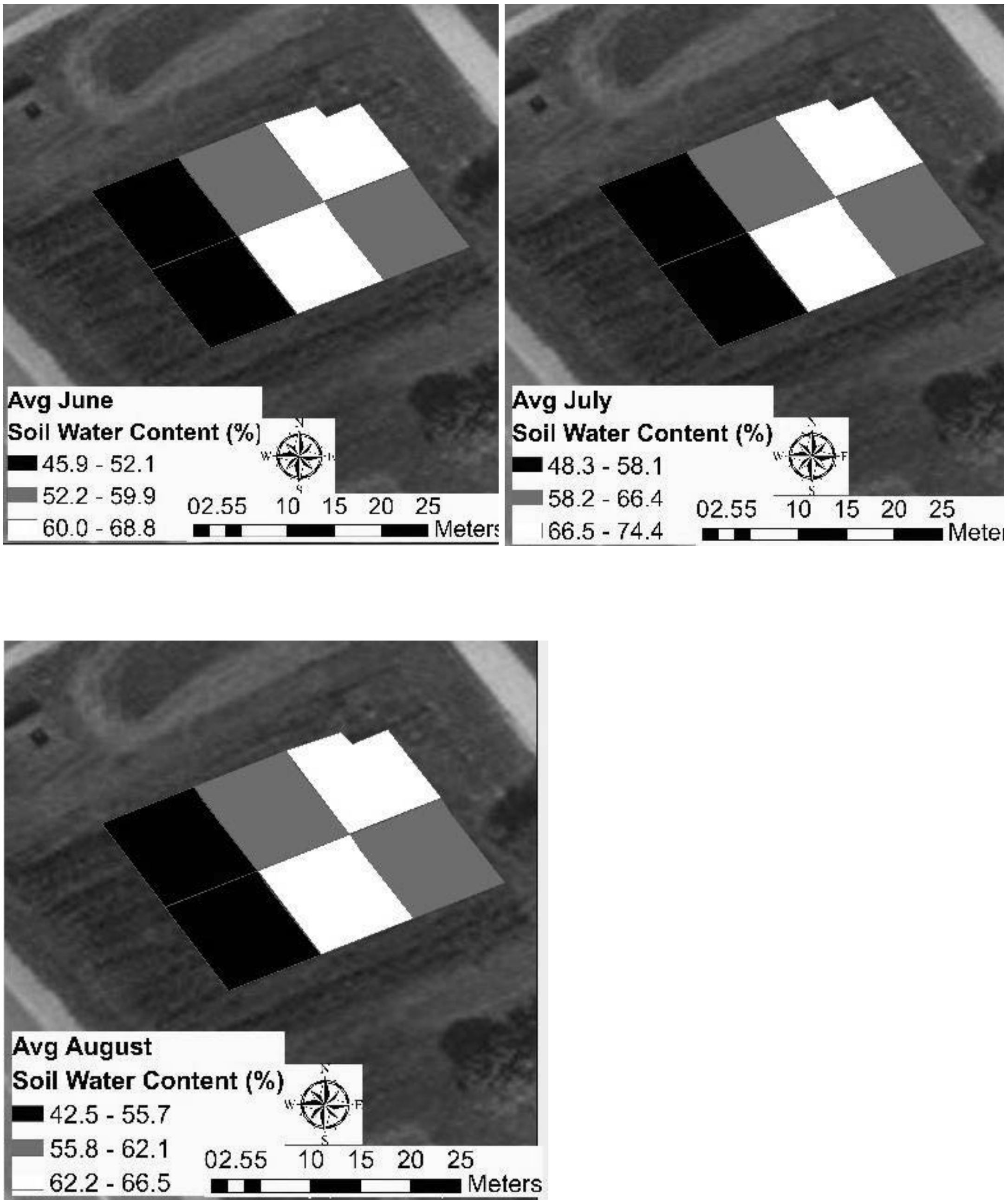

Fig. 3 Six experimental plots. One node was installed at each plot. Left: average swc in June, Center: average swc in July, Right: average swc in August. The grey scale color represents the average monthly swc in each plot. The darker the color the lower the swc and the opposite.

CONCLUSIONS

This study deals with sustainable irrigation and soil moisture monitoring systems. Thus, commercial soil moisture monitoring systems installed in six plots. The crop at the plots was hemp. The results demonstrated that swc variability remained the same in every growth stage of hemp. For this reason, it is very important to understand the soil moisture variability in every field using soil moisture monitoring systems. On the other hand, the vigor of the plants and the leaf moisture during the growing season did not depend on irrigation but on other factors that will be studied the following years. Finally, long-term soil moisture monitoring is needed to sufficiently clarify the results and conclusions of this study.

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