Testing Existing Prototypes of Conductivity Sensors for Monitoring the Concentration of Organic Fertilizers in Fertigation Systems

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Abstract— **Agricultural production has grown in recent years, increasing the use of Organic Fertilizers (OF). For that reason, the use of these compounds must be controlled in fertigation water. In this paper, we test three prototypes, using different combinations of coils, to determine the amount of OF in the water. A coil is powered by a sine wave of 3.3 peak-to-peak Volts for inducing another coil. The objective of this system is to detect different kinds of problems that can cause incorrect fertilization, which affects the sustainability of agriculture. We present the tests to verify the proper functioning of the prototypes. We test our prototypes by means of different dilutions of OF. The used concentrations of OF are between 0 and 20 g/l. We measure the conductivity for each concentration and the output voltage of our prototypes. The results show that prototype 3 is the one that has the best performance, obtaining 1.47 V of difference between the maximum and minimum output voltage and a good correlation coefficient. Finally, a verification test is carried out; the average error in the different samples tested is 0.2212%.**

Keywords - Coils; Conductivity; Organic Fertilizers; Fertigation.

I. INTRODUCTION

The use of fertilizer, pesticides, agriculture mechanization, and high-yielding varieties of plants have generated an increase in crop productions. This increase has produced a decrease in food prices and reduced world hunger. However, the use of fertilizer, pesticides, and large agricultural machines causes essential problems in the environment, which can cause a reduction in the production of harvest in the future.

The use of an incorrect technique of fertilizing can cause severe problems in the environment. These problems include: (i) nitrification of groundwater, (ii) pollution of surface water, (iii) transport of pollutants in soils, and accumulation of fertilizer in soils [1][2]. In addition, the excess of fertilizer causes an increment in the cost of maintenance of the crops without an increment of production. Traditionally, fertilizers are used without any control. Some farmers think that if production is poor, they need to use more fertilizer. However, the correct fertilizer is not being added even at the right points. For proper fertilization of the crops, the right quantity and type of fertilizer need to be used. If there is an excess of the fertilizer, this excess is not used by plants, and it accumulates in the soil or groundwater. In addition, the fertilizer can increment the concentration of limited nutrients in the soil. If a nutrient is limited in the soil, the plants cannot absorb the fertilizer by growing. This will cause an excess of nutrients in the soil because the nutrients are not absorbed by plants [3]. The limiting nutrient can be defined as the nutrient that is bioavailable in lower concentration than is used for growing biological organisms. This causes biological organisms to not grow even if they have sufficient concentrations of other nutrients. For this reason, it is essential that fertilization does not produce huge imbalances between the limiting nutrient and the other nutrients.

We can differentiate fertilizers using different criteria, such as: (i) Simple or multi nutrient fertilizers, depending if they are composed of one or more nutrients, (ii) Organic or inorganic, and (iii) Fast or Slow release. The use of fertilizer composed of one or more nutrients depends on the needs of the soil. Generally, it is recommended to use multi nutrient fertilizers. This is due to the fact that the increase of a single nutrient ends up creating new limiting nutrients. The fast-release fertilizers generate more pollution because they escape rapidly from the area when the plants cannot absorb them. Organic fertilizers commonly have slow release and they are multi nutrient. In addition, the use of wastewater sludge and compost of urban waste allows the recovery of waste materials. Finally, the use of organic fertilizer and water-saving politics have the potential to reduce the emission of N_2O (greenhouse gas) [4].

The use of sensors in crops has grown in the last years. Different works have been developed, such as wireless sensor networks for monitoring the state of the fruit, saving water, detecting disease, etc. [5]. This new trend is called precision agriculture and involves the inclusion of monitoring technology in agriculture (sensors, image processing, etc.).

In this paper, we propose an inductive sensor to monitor the use of organic fertilizer in irrigation. The selected prototypes have been previously used to detect the illegal dumping of wastewaters [6]. The proposed sensor is based on two copper solenoid coils. One coil is powered by alternative current and induces the other coil. We expect to have a variation on the value of the induced voltage according to the changes in the concentration of the organic fertilizer. Our sensor is located in the pipes that distribute the water in drip irrigation.

The rest of the paper is structured as follows. In Section 2, we present the related works. The methodology used in the experiment is presented in Section 3. The results of the different prototypes are presented in Section 4. Finally, Section 5 shows the conclusions and future works.

 ISBN: 978-1-61208-766-5

II. Related Work

In this section, we show different related work, and we explain the advantages of our system.

A solution for reducing the use of fertilizer is using a smart fertilizer. Feng et al. [7] proposed a controlled/slow-release fertilizer. This fertilizer is composed of polymer brushes of poly (N, N-dimethylaminoethyl methacrylate). Usually, slow-release fertilizers have increased discharge of nutrients with temperature and pH. This smart fertilizer has a slower release. A similar solution was proposed by Boli et al. [8]. They studied the use of slow-release fertilizer formulations basis of natural attapulgite, clay, ethylcellulose, film, and sodium carboxymethylcellu-lose/ hydroxyethylcellulose hydrogel. Their study concluded that the use of this fertilizer reduces nutrient loss, improves the use efficiency of water, and prolonges irrigation cycles. However, temperature, pH, and other soil properties can affect nutrient releasing. The paper indicated that the evaluation of soil organic matter content, soil texture, residual soil N, right irrigation strategies, and cropping systems need to be developed for reducing fertilizer use.

The use of slow-release organic fertilizers is a partial solution to the contamination problem. However, the farmers still ignore the amount of fertilizer that should be contributed to the field (except based on their own experience, without following technical criteria). To improve fertilization following technical criteria, some authors propose the use of sensors. Vijayakumar and Nelson Rosario [9] used different sensors for monitoring the water and fertilizer need. They used leaf wetness, soil moisture, soil pH, and atmospheric pressure sensors connected to 2.40 Hz MICAz mote, MDA300CA. The soil moisture sensor has been used for monitoring the water needs of the crop. For tracking the fertilizer, the system sends an SMS to the farmer with the pH value and it selects the amount of fertilizer. Zhang et al. [10] used the information of sensors in the crops and big data for determining the needs of water and fertilizer. The system is composed of 4 modules. The first one is the data acquisition system, the second one is the transmission data, the third is the big data layer, and finally, the fourth is the decision layer. The data acquisition is divided into a manual and automatic collection. The automatic collection is composed of a weather, soil, and crop growth sensors system. The manual collection used information about types of plants, the period of seedling, etc. These data are sent to a database with wireless technology. In the database, they are saved for future decisions. In the decision layer, the data are processed with irrigation and growing models for making decisions and to the historical archive of the crop data.

The use of inductive sensors has been reported in numerous scientific articles. Wood et al. [11] developed a system to measure the salinity. The system is based on two sensors: a temperature sensor, i.e., conductivity sensor, and a microcontroller. The two sensors are controlled by an Automatic Voltage Regulator (AVR) microcontroller that saves the data on a flashcard and sends the data. The conductivity sensor is composed of two coils in solenoid form (a powered and an induced coil) covered with 1-dodecanethiol protection against corrosion. The temperature sensor is used to adjust the values of conductivity to salinity. The maximum measure of the sensor is 67 g/l of table salt.

In other papers, Parra et al. [12] developed a system based on two coils for monitoring the conductivity in aquifers. They studied the different design of the coils that can be summarized in (i) changes in the number of spires maintaining the spires relationship. (ii) change the relation of spires. (iii) changes in the wire diameter (iv) change in the coil diameter. They concluded that the best prototype has 80 spires in the induced coil, 40 spires in the powered coil, a copper diameter of 0.4 mm, and 25 mm of coil diameter. Rocher et al. [13] demonstrate the use of coils for monitoring fertigation in crops. They compared the induced voltage caused by table salt and nitromagnesium (a fast release fertilizer). The different prototypes are composed of two coils (powered coil and induced coil) in a solenoid form. They concluded that prototypes with a powered coil of 40 spires and 80 spires in the induced coil are the better prototypes in the two studied salts. They found differences in the induced voltage depending on the salt that causes the conductivity. However, both papers did not study the use of organic fertilizer. It has less conductivity than inorganic salts, which can modify the behavior of the coil.

In these papers, we can observe the use of sensors based on coils for monitoring the conductivity of the water. As the inorganic fertilizer is composed of mineral salts, they suppose an increase in water conductivity. However, the OF is composed of organic components that provide less conductivity than inorganic fertilizers. Therefore, it is necessary to check if it is possible to measure the concentration of OF by using coil-based sensors.

III. Test Bench

In this section, we describe the materials used in the coils as well as the methodology used.

We created the coils with a PVC pipe, 3mm of thickness, and a diameter of 25mm. Moreover, the length of the PVC tube is 10cm. The copper used is enameled copper of 0.4 mm. We selected prototypes based on 40 spires in the Powered Coil (PC) and 80 spires in the Induced Coil (IC) from the previous works [12] and [13]. The copper is located on PVC pipe distributed in 2, 4, or 8 layers. The values of turns, layer numbers, and photography of the different prototypes are shown in Table I. Also, the copper was coiled in the clockwise direction in each one of the prototypes. This helps to maintain a similar basis for all prototypes and to obtain more relevant data. We power the coil in a clockwise direction, using the other end of the coil as a ground reference with a voltage of 3.3 Vpp, and we measure the induced voltage with an oscilloscope.

We have added a resistance of 47 Ohm in series to the PC. The induced coil has a capacitor of 10 nF in parallel. The model of the signal generator is AFG1022 [14], and the oscilloscope is TBS1104 [15]. The conductivity of the samples is measured with a conductivity model Basic 30 [16]. We tested it with concentrations of 0, 2.5, 5, 7.5, 10, 12.5, 15, 17.5, 20 g/l of organic fertilizer.

 ISBN: 978-1-61208-766-5

TABLE I. CHARACTERISTICS OF THE PROTOTYPES.

Prototype 1 (P1)	Prototype 2 (P2)	Prototype 3 (P3)
		
Spire: 40 PC 80 IC Layers: 2	Spire: 40 PC 80 IC Layers: 4	Spire: 40 PC 80 IC Layers: 8

In all tests, we prepared 500 mL of the sample that was introduced in a glass. The glass has a height of 16.2 cm and 8 cm of diameter. We used 6 out of 9 samples for calibrating the sensor. The other 3 samples were used for verification of the sensor functioning. In Figure 2, we can observe the experiment being carried out.

The induced voltage measurements have been taken by varying the value of the frequency in the signal generator. They have been tested in a frequency range of 10 to 300 kHz every 10 kHz. This process has been carried out for all the samples we have mentioned above.

IV. RESULTS

In this section, we show the obtained results of the different concentrations of organic fertilizer. Firstly, we test the prototype behavior in a specific spectrum of frequency. Next, we do the calibration of the sensors to verify the best R^2 (similarity between the mathematical model and the points we are trying to predict) with the obtained data. Then, we analyze the precision and exactitude of the results. Finally, we select the best prototype.

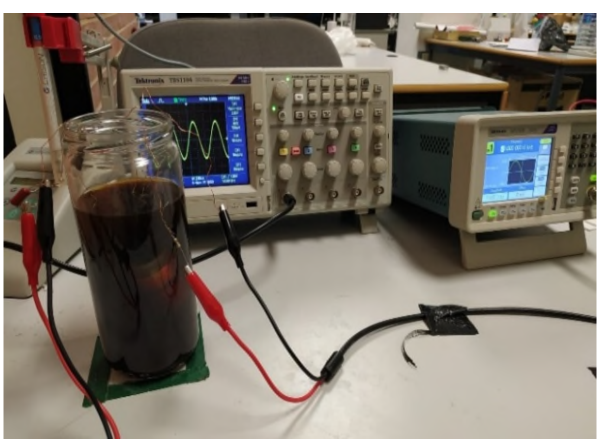

Figure 2. Experimental setup.

A. Prototype behavior

The first step is to analyze the response of the three prototypes that we include in this test. Therefore, three samples with different concentrations of OF are used. The objective of this part of the experiment is to find the Working Frequency (WF) of the sensors to use this WF for the calibration. The WF is the frequency in which the prototype has the maximum difference in the induced voltage between the lowest and the highest concentrations of the OF.

For this test, we used three samples of 0, 5, 20 g/l, respectively. We have used a maximum concentration of 20g/l due to the fact that the level of fertilizers does not usually exceed this threshold in the irrigation of the fields. Besides, the conductivity of the samples has been measured using the EC meter model Basic 30, which is a professional conductimeter, to obtain the most exact values. The results obtained with this device are 0.37, 1.13, and 6.14 mS/cm.

The obtained results with these prototypes are shown below. Figure 3 represents the results of P1. We can see that the range, in which the Magnetic Field (MF) generated by the coil shows more significant interaction, is between 90 and 110 kHz. Even though the peak is found at 100 kHz, the maximum difference of Inductive Voltage (Vout) between the lowest and highest concentrations is obtained at 90 kHz. Next, the behavior of P2 is displayed in Figure 4. According to Figure 4, the most sensitive region of the MF is between 90 and 130 kHz, with a peak at 120 kHz. The most significant change occurs at 110 kHz. Finally, in Figure 5, we present the portion of the spectrum in which the P3 works better. This range goes between 120 and 150 kHz. The peak is located at 140 kHz, which is the working frequency.

In the case of P1 at the WF, the lowest Vout is related to the smallest conductivity and the highest output with the biggest value of conductivity. P2 shows the same behavior as P1. Besides, P3 exhibits another way to work. In this case, the lowest conductivity is related to the highest Vout in Figure 5, and the lowest Vout is for the highest conductivity.

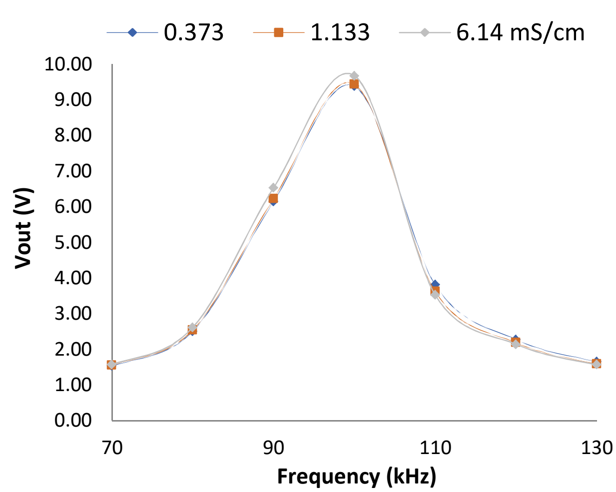

Figure 3. Representation of the frequency spectrum of P1.

 ISBN: 978-1-61208-766-5

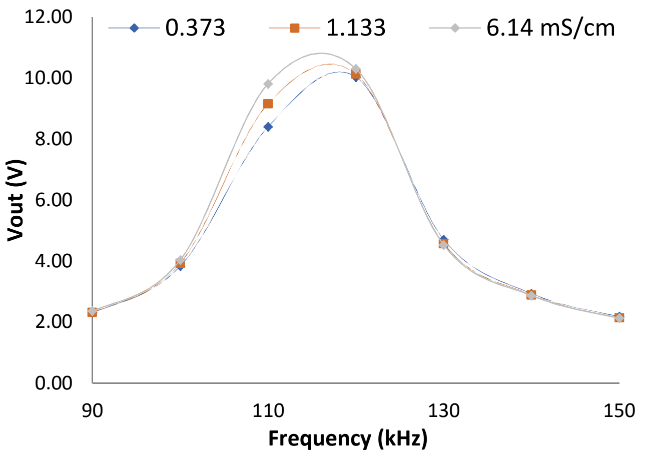

Figure 4. Representation of the frequency spectrum of P2.

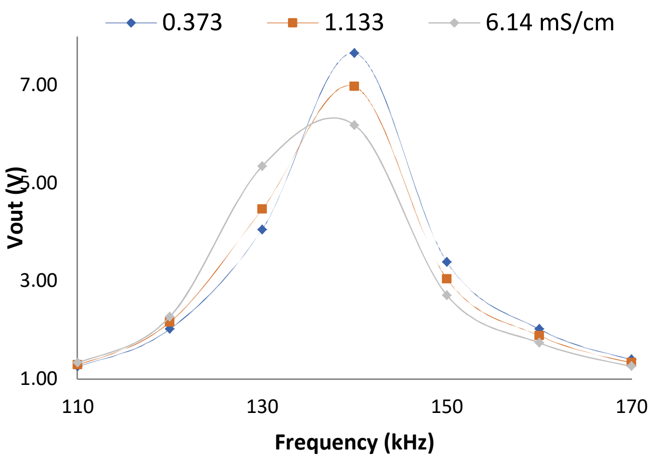

Figure 5. Representation of the frequency spectrum of P3.

All the prototypes showed a very similar range in which the generated MF and Vout are more sensitive to changes in the conductivity of the environment. Nonetheless, the way in which they respond to this change in the environment is different between them.

It will be necessary for these prototypes to perform some requirements in order to be selected as sensors:

- The Vout obtained must be as high as possible,
- The difference of Vout between the different quantities of organic fertilizer must be high (IV difference),
- The Vout for all tested dissolutions must be different, and
- The working frequency must be as low as possible (At smaller frequency cost decreases).

B. *Calibration of prototypes*

After scanning in a wide frequency spectrum, the results of the peaks for P1, P2, P3 have been analyzed. The highest difference of Vout between 0 and 20 g/l (IV difference) indicates the WF for each prototype, as can be seen in Table II. The three prototypes have been tested for their WF using the Statgraphics program [17]. Statgraphics is used to obtain the mathematical model for all the prototypes and observe how these adapt to the collected data. In addition, we use this program to calculate the confidence interval and the prediction interval.

The calibration of P1 is reflected in Figure 6. The best model which fits with the experimental points is the potential model. Besides, it has been realized the confidence interval and the prediction interval of the model that shows a good correlation between the *Vout* and the conductivity. Likewise, the model of P2 has been obtained. This is represented as a potential model (Figure 7). In this case, the confidence interval and the prediction interval are more separated from the model that describes the lowest correlation of the values than in the P1. Finally, the model of P3 is shown in Figure 8. The best fit model is an exponential model. In this prototype, the values of the output voltage decrease with the increase of the conductivity. The prediction interval and the confidence interval are more tithed than in the P2 ,but less than in the P1, although the correlation of the experiment point is excellent.

The *Vout* of the sensors is compared with the conductivity of the different concentrations of organic fertilizers. The mathematical models of the three kinds of prototypes are shown in (1)-(3).

TABLE II. WF AND IV DIFFERENCE IN THE PROTOTYPES.

Prototype	*Frequency(kHz)*	*IV difference*
P1	90	0.39
P2	110	1.41
P3	140	1.47

$$Vout\ (V) = \sqrt{36.1247 + 2.68502 * \sqrt{Conductivity\ \left(\frac{mS}{cm}\right)}} \quad (1)$$

$$Vout\ (V) = \sqrt{80.8549 + 9.15809 * \ln\left(Conductivity\ \left(\frac{mS}{cm}\right)\right)} \quad (2)$$

$$Vout\ (V) = e^{1.96023 - 0.0713772 * \ln\left(Conductivity\ \left(\frac{mS}{cm}\right)\right)} \quad (3)$$

The R^2 of the models are 0.9937, 0.9852, and 0.9923 for each prototype, respectively. This is a statistical parameter that indicates the adaptation of the model for each measured point.

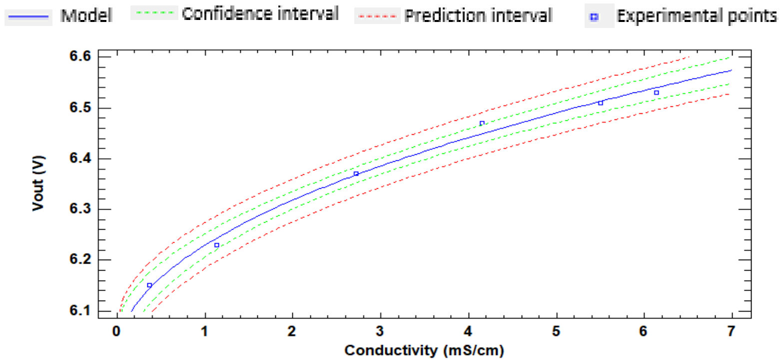

Figure 6. Tight model of P1.

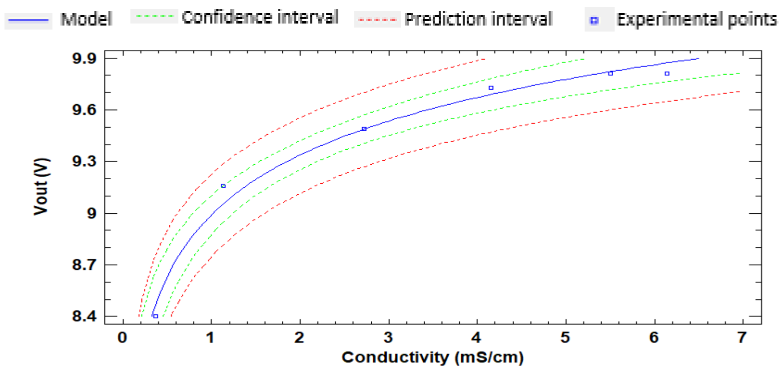

Figure 7. Tight model of P2.

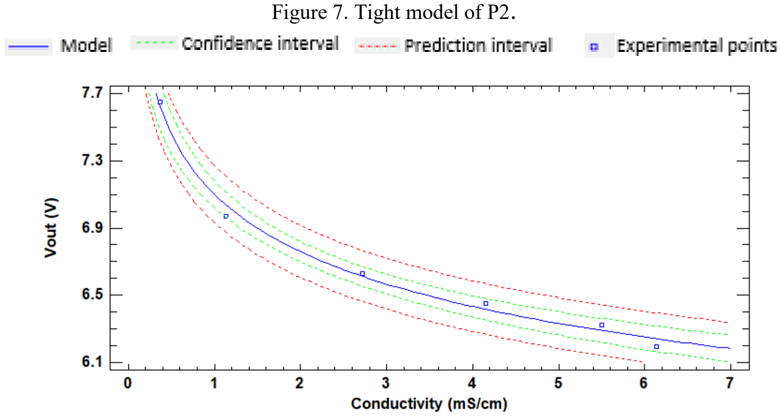

Figure 8. Tight model of P3.

C. *Accuracy of the values*

The last step is to obtain the verification of the prototypes P2 and P3. P1 has not been estimated because the difference of Vout between the lowest and highest concentration is under 1V. To obtain these results, we use the data of *Vout* and conductivity of our measurements on new samples of 5g/l, 10 g/l, and 15 g/l.

The values of Real Voltage (RV) and Model Voltage (MV) for P2 and P3 are represented in Table III. The RV is the *Vout* that was measured in the laboratory. Moreover, MV is the theoretical value according to the model of (2) for P2 and (3) for P3.

The absolute error and the relative error are calculated and represented in Table III. On the one hand, the absolute error is the difference between the Real voltage and the Model voltage. On the other hand, the relative error is the absolute value divided by the real value (in the two cases, it can be a positive or a negative value).

Our results indicated that P2 has 0.03 V of absolute error and 0.32 V of relative error. Meanwhile, P3 has 0.01 V and 0.22 V of absolute and relative error. As can be seen, the highest errors are found in P2, where the lowest error is in P3. This shows that P3 has the most significant accuracy of the values, unlike P2, which has the lowest accuracy.

V. CONCLUSION

In this paper, we presented an inductive sensor for monitoring OF in agriculture. The obtained parameters can be used to control the amount of OF that the irrigation water has.

TABLE III. ACCURACY OF THE VALUES

		P2		P3		P2		P3	
OF. (g/L)	**Conductivity (mS/cm)**	**Real (V)**	**Model (V)**	**Real (V)**	**Model (V)**	**Absolute error (V)**	**Relative error (%)**	**Absolute error (V)**	**Relative error (%)**
5.0	1.98	9.39	9.33	6.77	6.76	0.05	0.57	0.01	0.15
10.0	3.54	9.73	9.87	6.33	6.35	0.03	0.27	0.02	0.23
15.0	4.81	9.39	9.33	6.77	6.76	0.05	0.57	0.01	0.15
					AVERAGE	0.03	0.32	0.01	0.22

After we performed the measurements, we determined that the highest Vout is for P2, which shows a value of 9.81 V in the WF. P1 and P3 obtained 6.53 V and 7.65 V. Moreover, the biggest difference between 0 and 20g/l is given in P3, with 1.47V. In P1 and P2, the obtained results are 0.39 V and 1.41 V. Correspondingly, the lowest working frequency is presented in P1 in the 90 kHz, while the WF of P2 and P3 were 110 kHz and 140 kHz. Observing the absolute and relative error, the best accuracy is for P3, followed by P2.

Finally, we choose P3 as the best prototype to measure OF. Although the results of P1 are right, the difference between different concentration is very low.

In future works, we are going to study the effect of the extreme temperatures on the values of the measures. Furthermore, tests with different kinds of organic fertilizers will done.

ACKNOWLEDGMENT

This work has been partially supported by the European Union through the ERANETMED (Euromediterranean Cooperation through ERANET joint activities and beyond) project ERANETMED3-227 SMARTWATIR, by "Ministerio de Educación, Cultura y Deporte", through the "Ayudas para contratacion pre-doctoral de Formación del Profesorado Universitario FPU (Convocatoria 2016)". Grant number FPU16/05540, and by Conselleria de Educación, Cultura y Deporte with the Subvenciones para la contratación de personal investigador en fase postdoctoral, grant number APOSTD/2019/04.

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