INVESTIGATIONS ON A PRACTICAL DETERMINATION OF SOIL PH FOR AN IRRIGATION SYSTEM

INVESTIGAŢII PENTRU DETERMINAREA PRACTICĂ A PH-ULUI ÎN SOL PENTRU UN SISTEM DE IRIGAŢII

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Abstract. *A method and a device based on galvanic cell for practical determiation of soil quality deterioration under the action of water, nutrients, and pesticides are analyzed. The novelty lies in facilitating the input of measured data directly into an automated irrigation system via wireless communication. pH offsetting with temperature is provided. The research was aimed to investigate materials for electrodes construction and to calibrate the device with proper electrodes using known pH solutions.*
Key words: soil quality, pH sensor, galvanic cell

Rezumat. *Sunt prezentate o metodă şi un dispozitiv pe baza principiului celulei galvanice pentru determinarea practică a alterării calităţii solului sub acţiunea apei, nutrienţilor şi pesticidelor. Noutatea constă în facilitatea introducerii datelor măsurate direct într-un sistem automatizat de irigare prin comunicaţie fără fir. Compensarea măsurării pH-ului cu temperatura este posibilă. Cercetările au avut în vedere investigarea materialelor pentru construcţia electrozilor şi calibrarea dispozitivului realizat cu electrozii din materialele selectate utilizând soluţii cu pH cunoscut.*
Cuvinte cheie: calitatea solului, senzor pH, celulă galvanică

INTRODUCTION

In an irrigation system an undesirable effect that can occur is the alteration of the quality of the soil due to chemical changes caused by water on the mineral from the pre-existing structure or added as nutrients and pesticides, either in molecular form, H_2O or ionic form, H^+, OH^-. In large quantities H^+ cation causes a pronounced soil acidity, otherwise a lower value of the pH index (Mihalache, 2009). As known, pH is the opposite sign logarithm of the hydrogen ion activity in solution; pH is dimensionless and can have values between 0 and 14 on a logarithmic scale. Knowing the pH and keeping it within certain limits is important because it is an indication of the degree of assimilation of various macro and micronutrients by plants, because it determines the solubility of

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fertilizers. For example, in tomato crop it is recommended that water and soil pH should be between 6.0 ... 6.5 (Bejan, 2012).

For integration into an automated irrigation system dedicated to small and medium farms, from different ways of pH meaasurements there were considered those based on using a pH-meter with the ability to connect to a device for data acquisition so that measurements can be recorded and electronically stored for a period defined by the user. Other requirements were: measurement in a solution directly in the field, easy of use, automatic uploading of data in the irrigation system program, low cost of the pH sensor, unpretentious maintenance, alerts when critical threshold values are exceeded. Generally, since the pH values of the water and soil in agriculture are ranging from 5.5 to 7 or, according to other sources (Kohlmann, 2003), between 5 and 9, there are prerequisites to manufacture a pH sensor for a restricted scale based on methods involving lower costs.

Laboratory pH-meters with glass electrode are sensitive to the activity of the hydrogen ion from the solution, but the presence of other elements from the nutrients and pesticides may result in the generation of other ions (Na^+, $Ca2^+$, SO_4^{2-}) which limits the mobility of H^+ ions and, as consequence, to decrease the activity of H^+ ion. In this case the pH value is weighted with different coefficients which can be calculated or taken from tables (Dean, 1999).

MATERIAL AND METHOD

For an irrigation system rapid gathering of pH information is useful for the management of water quality and quantity provided in the field, for the alerting the farmer when threshold values are exceeded, so that it can intervene. To achieve this goal it is proposed a prototype of an electronic device for measuring soil pH, DpH, which must meet the following requirements: 1) to determine the soil pH of the aqueous solution created directly in the field; 2) allowing pH temperature compensation; 3) to submit the data to the irrigation controller; 4) have a minimum energy consumption; 5) have a low cost; 6) to comply with European Directives RoHS, REACH and WEEE. According to the requirements DpH consists of the following functional blocks (fig. 1): C - controller; SA - power supply; BC - communication block; ST - temperature sensor; SpH - pH sensor.

The main function of the controller block is to command the reading of the pH and soil temperature parameters. The primary information referring to the voltage corresponding to the pH and temperature of the solution at a given moment is transmitted to the irrigation control unit via the communication block. The main element of the block C is a microcontroller unit. There are On the market many offers for microcontroller circuits with extremely low consumption due to technologies such as: nanoWatt XLP, picoPOWER, ultra-low-leakage. Some examples: STM32L4, ultra-low power MCUs (STMicroelectronics) 170nA power consumption in standby mode with the retention of data stored in volatile memory, RAM; MSP430FR50XX, ultra low-power MCU, "Wolverline" (Texas Instruments), 360nA power consumption in standby mode while maintaining the function of real-time clock, RTC, with less than 100µA/MHz power consumption in active mode, PIC24FJ64GB004 (Microchip) 220nA in standby mode with RTC functionality, but with 250 µA/MHz power consumption in active mode and PIC16LF1509 with 30µA/MHz power consumption in active mode;

SMART SAM L22 (Atmel) 490nA in standby mode with RTC functionality, 39μA/MHz power consumption in active mode. The choice of a solution must consider several aspects besides energy consumption: communication interfaces, the capability of analog signal processing, data and program memory size, cost, availability of a development environment, technical support.

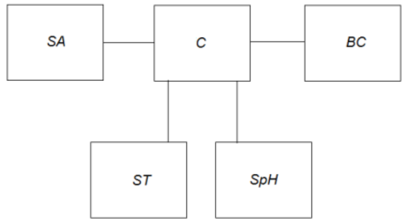

Fig. 1 Block diagram of the pH measuring device, DpH

The communication unit converts the information into an electrical signal which is adapted to the environment whereby remote transmission is carried out. This can be done by wire, but it is a complex and expensive solution, or wireless. There are several communication technologies by transmitting radio frequency narrowband or spread spectrum radio transmissions. A list of technologies that have found applications in agriculture and environmental surveillance is given in (Atasasov, 2013): ZigBee, Wi-Fi, RFID, GSM-SMS, Bluetooth. In recent years another available technology is LoRa that comes with a low power consumption and a high range of coverage (over 15km), while having a low cost. SX1272 and SX1276 (Semtec), RN2348 (Microchip) are among the first circuits (transceivers, modem) in this technology.

SA block has to ensure the a stabilized voltage to the electronics (microcontroller, transceiver, ADC, etc.) which is obtainted from a rechargeable battery; generally, working voltages are higher (2.7V ... 3.6V) than the supplied battery (0.9V ... 1.2V) so it is necessary a step-up DC converter.

ST block is constituted by a temperature sensor which must be placed as closed as possible to the one of the electrodes of the pH sensor. Interconnection with the control block is wired depending on the type of sensor. The narrow temperature range is suitable for to the use of cheaper integrated thermocouples with the possibility of direct interconnection to a microcontroller ports. LM95071, TMPx75-Q1 (Texas Instruments) support standard serial communication on 3 and 2-wire, SPI, Microwire or STMBus, I2C, but requires two additional wires for power. DS1821 (Maxim Integrated) requires only a single wire interface, 1-wire, plus two for supply (or just one, V_{DD} in "parasite power" mode, if DS18S20 circuit).

SpH block is dedicated to the conversion of the hydrogen ion activity in a solution into a measurable electrical signal. A simple method for determining pH is based on measuring the current flowing through the galvanic cell consisting of two electrodes inserted into the aqueous solution of soil constituting the electrolyte. The nature of the electrode materials is decisive for electrochemical potential which is specific to each material. The drop of voltage resulting from the passage of the current through a resistor is applied to an analog-to-digital converter, then the numerical value can then be stored, transmitted remotely, processed.

The proposed DpH (fig. 2 b) is built around the very low power microcontroller MSP430F2274 (Texas Instruments) with integrated analog-to-digital converter. The measured voltage is sent remotely via the CC2500 transceiver (Texas Instruments) working in the 2.4GHz ISM band using a proprietary protocol, SimpliciTI. Soil temperature measurement circuit is done through the digital thermometer DS1820 (Maxim Integrated) by 1-wire communication. The power supply for electronics is obtained from a rechargeable NiMH battery 1.2V/2700mAh through a DC converter based on a boost converter circuit MCP1642 (Microchip). This approach allows the pH sensor integration into a local wireless sensor network (WSN) to be driven by the automatic irrigation system.

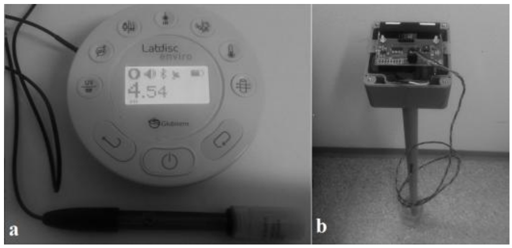

Fig. 2 Devices for pH measuring: a) the reference, b) the prototype, with attached temperature sensor

Experiments considered for validation of the method and device have the following objectives: 1) choice of materials for the construction of electrodes so that for the entire pH scale the current flow does not change the direction through the circuit and the correlation between pH and voltage measurements to be bi-univocal; also, the trip of measured voltage values must be sufficient to achieve good accuracy (tenths of pH); 2) establishing the correlation between pH and the voltage drop measured in mV using aqueous solutions with known pH; 3) pH temperature compensation; 4) determining the pH of the soil samples under laboratory conditions having a known pH; 5) pH determination in real field. DpH conversions pH/mV are carried out every 10 seconds, but convertions mV/pH is achieved by the remote processing unit after passing a time required to stabilize the dissociation reactions (determinations were made after 5, 15, 25, 30 and 60 minutes) by averaging 10 successive samples. The aim is to establish voltage thresholds for tabulation of the measurements.

Used instruments: digital multimeter, DVM4200, Velleman; data logger with pH sensor, LabDisc Enviro, Globisens (fig. 2 a); Latitude D830 laptop, Dell.

RESULTS AND DISCUSSIONS

Using three substances (deionized water, caustic soda and acetic acid food grade) were obtained solutions with various concentrations of ions of which pH was firstly determined with the reference device. By using electrodes made of various materials was studied the change in potential provided by the galvanic element according to the pH of the solutions. Materials for electrodes used were: stainless steel (OL304), aluminum, copper, titanium, gold, tin-copper-nickel alloy, copper-zinc (brass), zinc-aluminum-copper (zinc alloy), tin-copper-nickel-germanium alloy (SN100C).

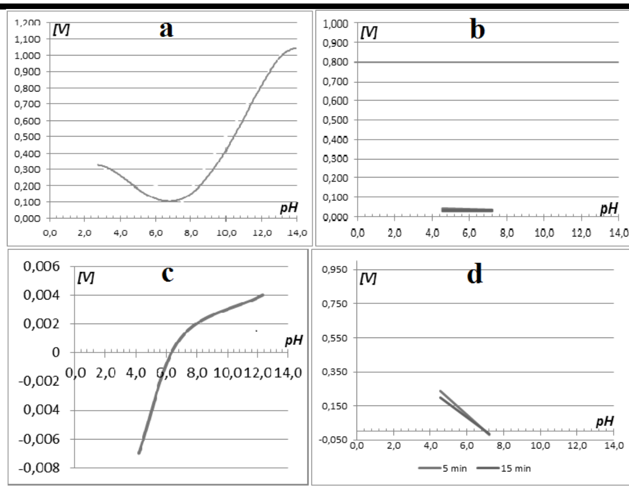

Fig. 3 Voltage between the electrodes variation depending on pH: a) steel - aluminum, b) steel - brass; c) steel - copper, d) brass – titanium

Steel was the first choice because this material being used to the humidity sensor for the automatic irrigation system it could be a possibility to construct a multi-sensor device including the measurement of soil pH (Codreanu *et al,* 2014). The analysis of the voltage vs. pH graphs shows different behaviours for pairs of electrodes: steel-aluminum: the non bi-univocal correlation (fig. 3 a) does not allow detection of acidic/basic character for some voltage values; steel - brass: almost constant voltage variation measured in the pH range of interest (4.2...7.5) makes impossible to highlighting acid to neutral character; copper-aluminum: the trip of voltage values measured for solutions with pH>7 is increasing and very convenient for achieving good accuracy (from 0.312V@pH3.96 at 1.303V@pH13.82), but for pH<7 the variation curve is decreasing; steel-copper: variation is monotonous (fig. 3 c), but for acidic solutions voltage values are negative, while for the basic solutions they are positive; brass-titanium: voltage is decreasing from acid to neutral and becomes negative for pH>7 (fig. 3 d);

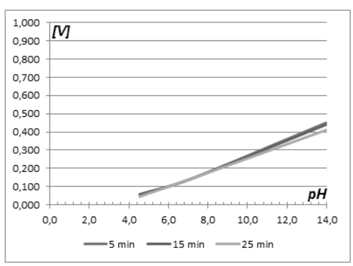

Fig. 4 Voltage variation between the electrodes vs. pH for copper – brass

brass - SN100C: presents too low values for good accuracy; gold-aluminum: presents a maximum for highly basic solutions (1.119V@pH12), but it is too expensive; copper-brass: monotonically increasing variation (fig. 4), almost linear in the pH range 4.55…14, quite stable values over time (determinations at 5, 15 and 25 minutes). The composition of this type of brass according to the Spark Optical Emission Spectrometer analysis from LISEOFRX Laboratory is: Cu 57.3%, Zn 34.07%, Pb 5.14%, Sn 1.53%, Fe 0.60%, Sb 0.394%, Ni 0.361%, Al 0.183%, As 0.160%.

CONCLUSIONS

1. The pair of electrodes copper - brass meets the conditions necessary for voltage - pH bi-univocal conversions in the practical range of interest.

2. All experiments were conducted at ambient temperature 25^0C (298.15K), however, since soil temperature may reach up to 65^0C (338.15K) in full sun, temperature compensation measurement is required to perform the calibration of the pH sensor and values tabulation for conversion. They will be the subject of the next research.

3. Inclusion of the DpH in an automatic irrigation system for small and medium farms allows automated processing of measurements exactly at the predetermined time interval, required pH temperature compensation, reporting, alerting messages (IoT capability).

4. To increase the safety communication transmission due to the specificity of the field (vegetation, low height of antenna above ground) will be considered the use of LoRa technology.

***Acknowledgments**: ThisThis paper was published under the frame of the “Partnerships in priority areas” (PN II) Romanian Research program, developed and supported by MEN-UEFISCDI, SIOPTEF project, PN-II-PT-PCCA-2013-4-1546, no. 58/2014.*

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