A PORTABLE ROVER AS A TOOL FOR SOIL WATER MONITORING

Ioannis GRAVALOS[1], Theodoros GIALAMAS[1], Avgoustinos AVGOUSTIS[1], Dimitrios KALFOUNTZOS[1], Martin LIBRA[2]

[1]*School of Agricultural Sciences, University of Thessaly, Greece*
[2]*Department of Physics, Faculty of Engineering, Czech University of Life Sciences Prague, Czech Republic*

Abstract
Advances in soil water content (SWC) monitoring technology continue to provide new and significant benefits to agriculture. An innovative approach for observing SWC is introduced using a portable rover platform traveling through in-ground horizontal access tubes and monitors the SWC in real time. A series of tests for evaluating the prototype portable rover were designed and conducted. It demonstrated very good mobility and produced records of the SWC in different horizons. The recorded values were then plotted as three dimensional (3D) patterns with high accuracy. The results show potential applications for this sensing approach, yielding horizontal monitoring of soil water in the root zone or deeper subsurface.

Key words: *soil water status; monitoring locations; rover platform; access tubes.*

INTRODUCTION
Soil water content (SWC) is an indicator of the amount of water in soil and an important factor on many biophysical processes. It affects the plant growth and nutrition, nutrient transformations in the root zone, microbial decomposition of the soil organic matter, etc. (*Bitteli, 2011*). There are two common methods to measure soil water status: direct and indirect. Gravimetric is the only direct method to determine how much water is in the soil. The volumetric and tensiometric (water potential) are indirect methods because they measure other properties of the soil that vary with water content. Most of the available soil water measuring instruments (sensors and probes) are based on indirect methods for measuring the soil water status.
Charlesworth (2000) & Muňoz-Carpena (2004) present several field devices which measure SWC, such as the Time-Domain Reflectometry (TDR), Frequency Domain Reflectometry (FDR), etc. The application of TDR technique to soil water measurements was first reported by *Topp et al. (1980)*. This research linked the measured travel time of an electromagnetic wave with the soil water (θv). FDR soil water sensing systems operate at relatively low frequencies. They are affected by salinity, clay and organic matter, water content, bulk density, temperature, compaction and texture (*Evett & Parkin, 2005; Evett et al., 2006; Paltineanu & Starr, 1997*). FDR sensors are portable, can be used with access tubes, unattended, and can also be automated and multiplexed, while their initial costs may be lower than those of TDR systems or neutron meters. However, a bad soil-sensor contact or small disturbances of the soil around the sensor have a negative impact on the sensor performance (*Fares et al., 2004*).
Gravalos et al. (2012) proposed horizontal monitoring of SWC using a mobile electromagnetic sensor-based platform that moves in access tubes. This integrated system included a soil water sensor and two circular articulated wheeled bases, each of them driven by a small wheeled electric motor. The recorded values of SWC allow the composition of two-dimensional (2D) or three-dimensional (3D) images with high accuracy and on a large scale *(Gravalos et al., 2013)*. *Sun et al. (2014)* also presented an alternative prototype, in which an EM sensor moves through a horizontal access tube while measures SWC distribution at a fixed depth. Two cabled pulleys were affixed to and driven by two individual motors, one being a stepper-motor and the other a dc-motor. During a given scanning event, the stepper motor turned counterclockwise to proceed the sensor in 5 cm increments along the X-axis. Meanwhile, the dc-motor turned clockwise with some resistance against the drawing force to maintain tension on the nylon string. When the mobile sensor reached a Hall-switch at the right end of the tube, the dc-motor reversed direction and retracted the nylon string drawing the sensor back to the starting point.

In this paper, we present the design and prototyping of a portable rover platform that carries a capacitance sensor for easy accessing in an in-ground tube for horizontal monitoring of SWC.

MATERIALS AND METHODS

The schematic illustration of the prototype rover platform that travels through the in-ground access tubes and monitors the SWC is shown in Fig. 1(a). It was constructed with a modified commercial soil water sensor (*Diviner 2000, Sentek Pty Ltd, Stepney South Australia*), placed on two articulated wheeled bases, which are linked via universal joints. The body of the wheeled bases is circular in shape, and it serves to support the driving and sliding wheels. The driving wheels are supported via bumper suspensions. The suspension system allows motion only along the vertical direction and relies its function on flexible members (compression springs), to hold the bumper loosely in place. The deflection of the bumper suspension gives foldable characteristics to the driving wheels, which maintain steady contact with the access tubes. This way, whether it is for straight or curved tubes, the rover platform is always guided to the direction of them. Two motors are engaged in the rover movement. These are high quality DC motors that are installed close to the driving wheel parts. The total length of the rover is 235 mm and its outer diameter may vary from 48 mm to 54 mm. The dynamic behavior of the rover platform was described in detail in reference to *Gravalos et al. (2017)*. In addition, the portable version of the rover platform (Fig. 1(b & c)) includes a stainless steel cable reel (770(L) x 371(W) x 810(H) mm). The electronic control module of the rover platform is installed in the cable reel. It contains all the drivers necessary to drive the motors and allows the speed to be controlled in both the forward and reverse directions.

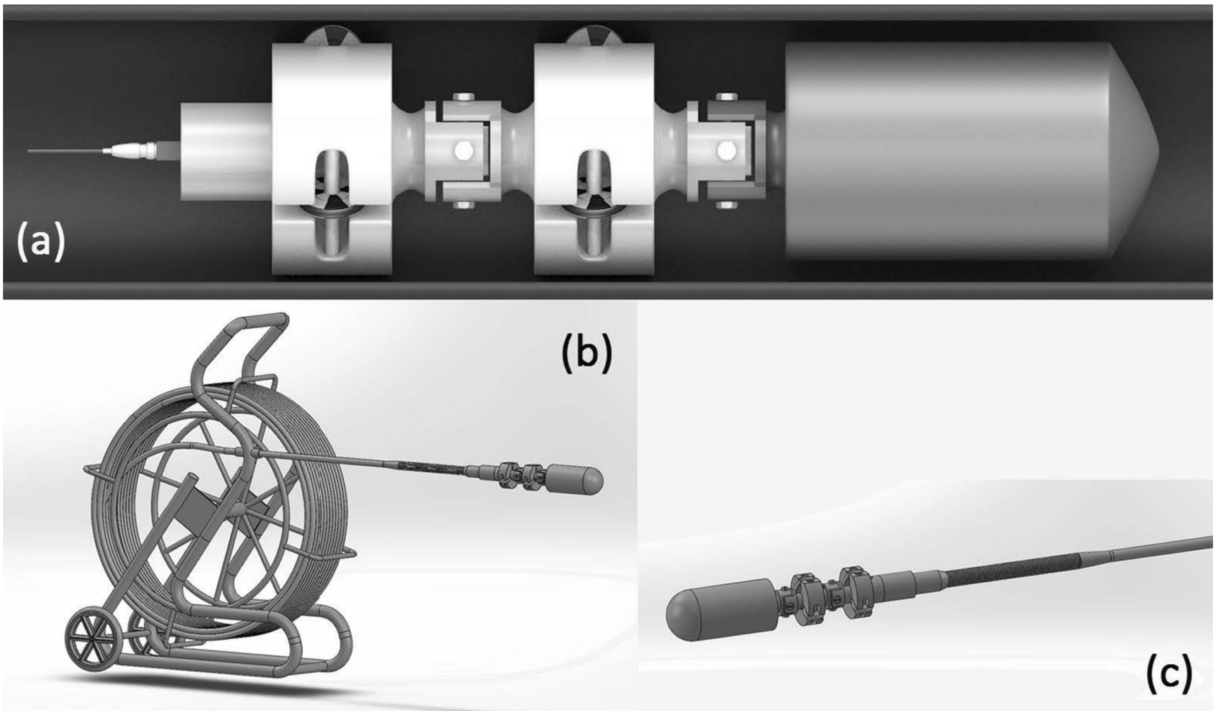

Fig. 1 (a) The schematic illustration of the prototype rover platform, (b) and (c) The portable version of the rover platform for easy accessing in in-ground access tubes.

The experimental tests were conducted in a field plot (1.5 m long and 1 m wide) at the School of Agricultural Sciences, University of Thessaly, Larissa (Greece). Analyses of the soil samples were performed, including: soil particle size distribution (sand 41%, silt 25%, clay 34%), bulk density (1.33 $g.cm^{-3}$), water retention characteristics (field capacity 27 vol.% and permanent wilting point 13 vol.%) and electrical conductivity (EC) of 0.20 $dS.m^{-1}$. In addition, three PVC access tubes were placed horizontally, along the field plot, at a depth of 0.15 m under the soil surface, and at uniform distances. In order to build a good knowledge of SWC conditions within the root zone requires measurements to

be taken at several locations. SWC measurements within the root zone can be used to evaluate soil water available to the plant, while deeper measurements below the root zone can show the deep percolation of water. The shallowest SWC measurements should be about 10-15 cm below the surface, while the deepest should be at least 20% deeper than the bottom of the plant's root zone. Special attention was paid to the installation of the tubes in the soil, in order to avoid air pockets between the tubes and the soil. The irrigation occurs only when the daily mean SWC is below the refill point of 0.18 $m^3.m^{-3}$ and this only in locations with a SWC lower than that limit. After 6 weeks of experimental procedure with the above irrigation constraints, 88 mm of water was applied to the total surface of the field plot. Water was distributed across the field plot through manual labor and watering cans.
Calibration of the Diviner 2000 sensor was done under laboratory conditions. The calibration equation was derived from regression analysis of sensor measurements of scaled frequency (*SF*) against the soil water θv, according to *Groves & Rose (2004)*, *Giraldi & Iannelli (2009)*.
The observations of SWC were conducted every day for a period of 6 weeks. The portable rover platform measures the SWC at fixed positions of the access tube spaced out every 24 cm of length increment (move-stop-measure case). Thus, for the 3 access tubes a total number of 18 measurements are conducted where every single value is the average value of three readings. A sensor data logger is the data storage, display and conversion device. Then it was connected to the laptop via a standard serial port. A software application is used to download and store data in a backup file or to export backed up data to a comma-separated variables (CVS) file format. This text-based file format can be viewed and analyzed with a third party software.

RESULTS AND DISCUSSION

Box plot of Fig. 2 compares the distributions of SWC between 18 fixed positions of the field plot over the 6 weeks of experimental procedure. At first glance more boxes seem to balance around refill point or to have higher SWC except the boxes of the fixed positions 1, 5, 12 and 17 that shows the lower values of soil water content. In addition, the box of position 4 shows the highest values of SWC much greater than the field capacity. If we ignore the outliers, the variation in the more boxes is very short and similar, except the boxes for fixed positions 4, 9, 10, 15, and 16 whose interquartile range is larger.

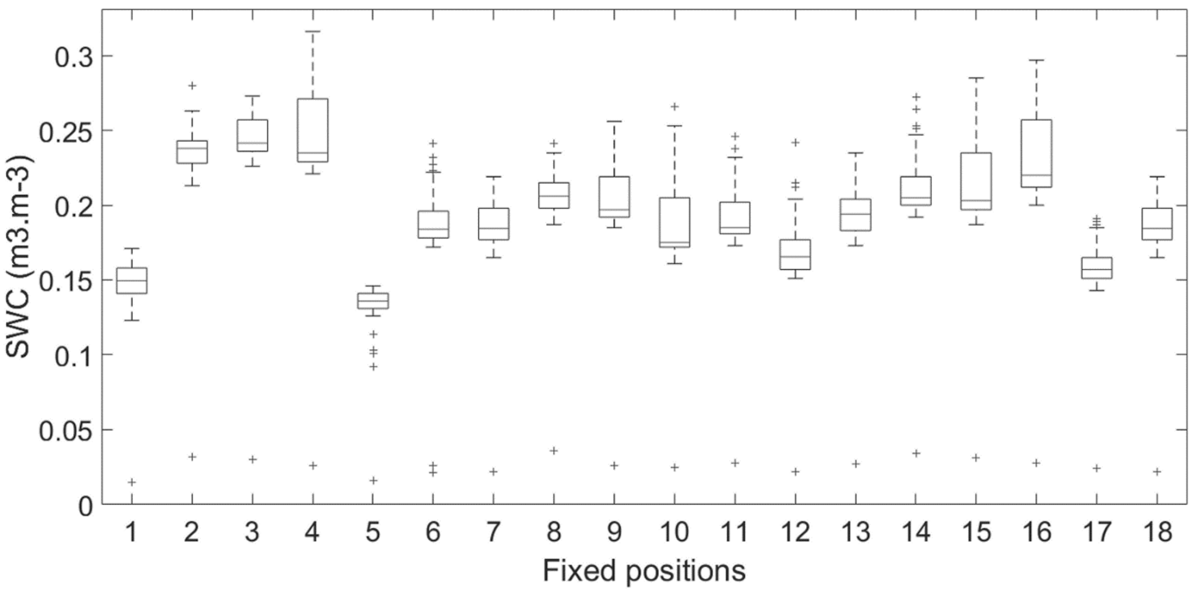

Fig. 2 Box plot of SWC for the eighteen fixed positions of the field plot over the 6 weeks.

Fig. 3 depicts 3D patterns of SWC observed by the rover platform. Each pattern represents a different week (1st until 6th week). The distribution of SWC was characterized by a significant difference between poorly and well-drained regions of the field plot. The soil water did not uniformly infiltrate

downwards but selectively penetrated the deepest layers, according to how good was the spatial drainage system. The SWC fluctuated between 0.01 and 0.316 $m^3.m^{-3}$ in the entire subsurface of the field plot. We may conclude that the variable drainage system in the plot or the soil physical conditions or both control water movement. This information is very useful for precise crop irrigation scheduling.
The combination of portable rover platform moving inside in-ground access tubes is a new approach that allows topological extension of SWC readings and aims at the creation of 2D or 3D soil water images across or along the investigated field plot. Furthermore, it provides an interesting perspective for the assessment of soil water distribution at different horizons of vertical soil profile (we assume that PVC access tubes are installed at different soil depths). It offers quantitative and qualitative spatial soil water data at large scale (>1 m^2), which is not possible with other methods and instruments that only provide local SWC readings. Comparing the results of this method to the much smaller sampling volumes of the sensors or probes installed in predefined points into the soil profile gives an idea of the amount of instrumentation that would be needed if these devices were to be used in order to get precise patterns of the SWC.

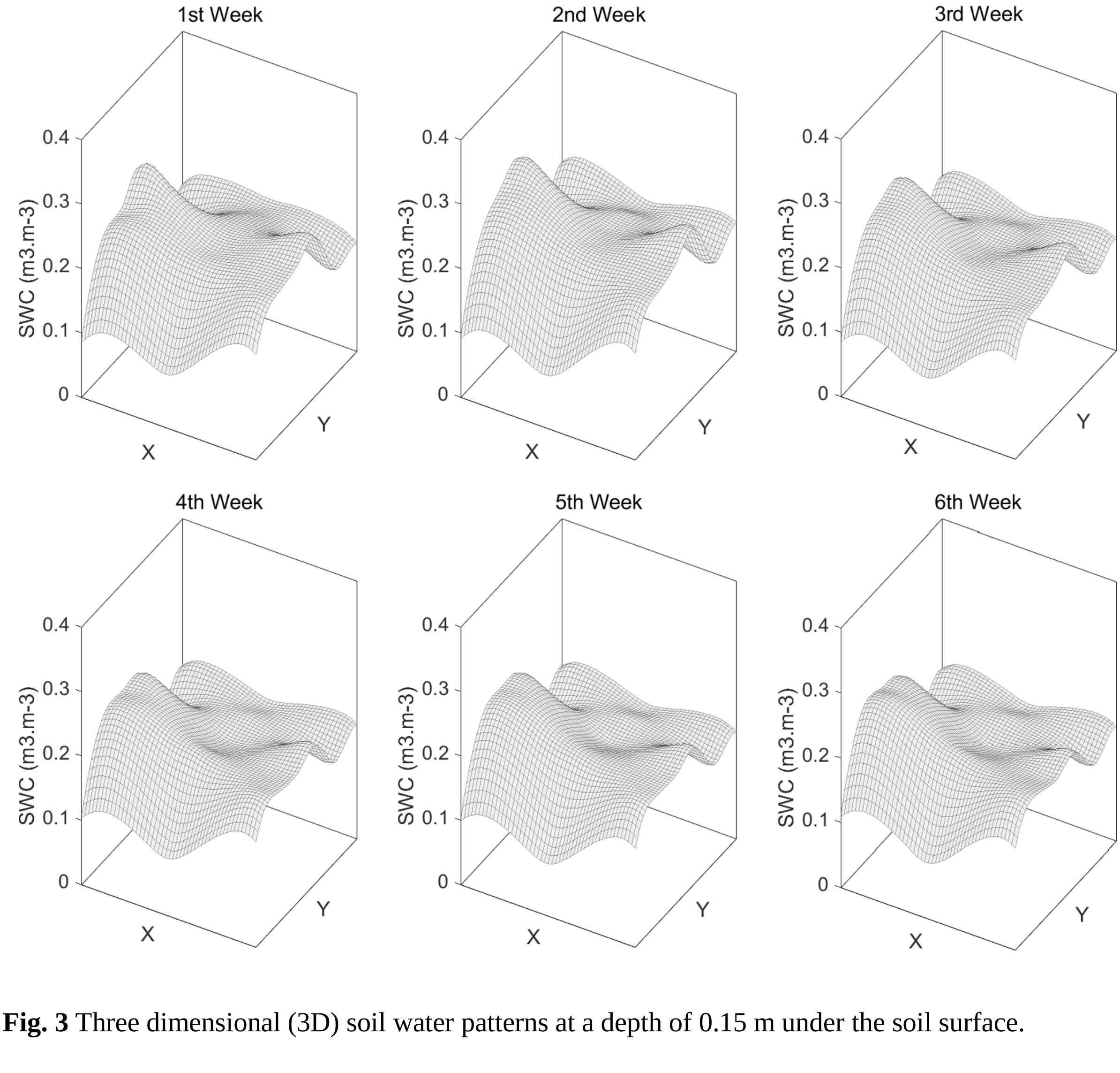

Fig. 3 Three dimensional (3D) soil water patterns at a depth of 0.15 m under the soil surface.

The proposed rover platform for imaging spatial SWC is thus a very attractive alternative. Soil water images will play an increasingly important role in the control of resource gradients, such as, soil water and nutrients and therefore for determining field vegetation patterns. The rover platform method depends on the choice of the capacitance sensor (Diviner 2000). This type of sensor is less accurate than other types due to changes in soil bulk electrical conductivity (including temperature changes) that

often occur in irrigated soils. However, by using sensor specific soil water calibration, the rover platform method could easily become a standard measurement procedure. Alternatively, the capacitance sensor (Diviner 2000) could be replaced by other types of sensors of higher accuracy. Some of them can be easily adapted to the rover platform and have suitable form and dimensions so that they can move in the access tubes with no further modification. Furthermore, being impractical to implement calibration against gravimetrically observed data on a constant basis, meaning that the sensor performance cannot be always guaranteed, geostatistical interpolation methods could be used to interpolate these data, while the actual sensor measurements could be used as a secondary source of information (*Vanderlinden et al., 2008*).
A review of the relevant literature indicates that a satisfactory number of soil water monitoring geophysical methods and technologies are available nowadays *(Galagedara et al., 2003; Grote et al., 2003; Lunt et al., 2005)*. In recent years, some researchers used electrical resistivity systems to monitor soil water changes (*Aizebeokhai and Olayinka, 2010*). The spatial distribution of the SWC may also be determined by measuring the bulk soil electrical conductivity (ECa) using non-contacting electromagnetic induction (EMI) instruments. As a future project, field comparative studies need to be carried out so that the proposed rover platform is directly compared to other geophysical methods so that reliable conclusions about their effectiveness and accuracy can be drawn.

CONCLUSIONS

The series of tests have proved that the portable rover platform presented in this study can function effectively inside the in-ground access tubes. It is a new and cost effective way for efficient irrigation water management because it can cover a large irrigated area, and offers rapid and easy measurements. Compared to the majority of the commercial dielectric sensors and probes, which are installed in fixed predefined points into the soil for a long time, the proposed rover platform has a significant advantage, because it is able to record the actual soil water content in horizontal, vertical or other orientation. It can also record the spatial variability of the water content, so that precise information about the soil and plant environment can be gathered.

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Corresponding author:
Prof. Ing. Ioannis Gravalos, CSc., School of Agricultural Sciences, University of Thessaly, Larissa, 41110, Greece, phone: +30 2410 684216, e-mail: gravalos@teilar.gr