# Optimizing Soil Moisture Uniformity and Irrigation Management

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**Abstract.** This research is a study on the relationship of irrigation water treatments and soil moisture distribution uniformity (DU). Soil moisture distribution was based on long-term data sets that were collected during wet and dry soil conditions (from permanent wilting point to field capacity) using a novel electromagnetic sensor-based platform moving inside subsurface horizontal access-tubes. The irrigation treatments regarding two case studies under dry and wet soil conditions were conducted for a period of 115 days and 110 days respectively. In dry soil conditions, the irrigation water treatments strongly affect the DU of soil moisture that can be achieved constantly using variable rate irrigation treatments. On the contrary, the DU of soil moisture in wet soil conditions was maintained at a high percentage and was slightly affected by irrigation treatments. However, obtaining accurate soil moisture information at a large scale over a long period can be used to improve water use efficiency.

**Keywords:** precision irrigation scheduling, sensor-based platform, uniformity.

## 1 Introduction

The main methods used to describe soil moisture content are gravimetric, volumetric and depth of soil moisture per depth of soil. Many instruments exist for measuring and monitoring soil moisture content and they are summarized as follows: neutron moisture meter, tensiometers, electrical resistance blocs, and dielectric sensors and probes. Dielectric sensors and probes have gained wide acceptance over the last years. This group of sensors and probes determines soil moisture content by measuring the dielectric constant of soil (Muñoz-Carpena, 2004).

Soil moisture content is highly variable in time and space. Soil moisture variations are affected by different factors such as soil texture, topography, crop cover, climate parameters and irrigation practices. Soil moisture variability is very important to understand soil moisture redistribution after rain or irrigation event, infiltration, evapotranspiration and pollutant transport. Various sensing approaches have been developed for measuring spatial and temporal soil moisture variability, including soil

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moisture sensor networks, geophysical methods (Hu et al., 2011) and remote sensing techniques (Moran et al., 2004). A novel horizontal access tubes sensing system for monitoring soil moisture variability using an electromagnetic sensor-based platform was first proposed by Gravalos et al. (2012).

The objective of the study reported here was to investigate the effects of uniform rate irrigation and variable rate irrigation on soil moisture distribution and give recommendations for improved irrigation scheduling and the design of automatic irrigation systems. Soil moisture distribution is based on long-term data sets that were collected during wet and dry conditions (from permanent wilting point to field capacity) using a novel electromagnetic sensor-based platform moving inside subsurface horizontal access-tubes with the task of monitoring the soil moisture distribution.

## 2 Materials and Methods

Experiments were carried out under laboratory conditions in the Department of Biosystems Engineering at the Technological Educational Institute of Thessaly (Greece) during a period of eight months. In the laboratory room, the ambient temperature was kept nearly constant (≈22 °C). For the soil moisture monitoring experiments, an artificial soil tank was used and rigid polyvinylchloride (PVC) plastic access tubes. The soil tank was made of water-resistant wood, having dimensions 1.44 m long, 1.10 m wide, and 0.25 m deep (total volume 0.4 $m^3$). The three PVC access tubes were placed horizontally, along the soil tank, at a depth of 0.15 m under the soil surface, and at uniform distances. The type of soil used for all series of experiments was clay loam. The total surface of the soil tank was divided using a wood frame into 36 (3 columns x 12 rows) equal cell-rectangles. The wood frame was used for the trapping of applied water in the individual cell-rectangles and thereby ensuring uniform distribution of irrigation water.

A schematic illustration of the prototype electromagnetic sensor-based platform that travels through subsurface access tubes and monitors the soil moisture content is shown in Fig. 1. It was composed of a modified commercial soil moisture sensor (Diviner 2000), which was placed on two articulated wheeled bases. The sensor-based platform is presented in detail elsewhere, see Gravalos et al. (2012). According to Sentek Pty Ltd. (2007), the Diviner 2000 sensor recorded moisture from a soil volume outside the access pipe, which had a sphere of influence of: (a) 100 mm horizontal length, and (b) 50–100 mm radial distance from the outer wall of the access pipe.

The electromagnetic sensor-based platform recorded the soil moisture content at fixed positions of the PVC access tubes spaced out initially at 6 cm and then every 12 cm of length increment (move-stop-measure case). Each position corresponded to the center of each rectangle. Thus, for each access tube a number of 12 measurements have been conducted where every single value is the average value of three readings. By use of a data display unit and a personal computer, the soil moisture content was determined at each position one time per day.

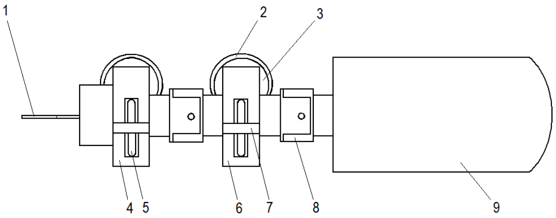

**Fig. 1.** Schematic illustration of the electromagnetic sensor-based platform. (1) towing hook, (2) driving wheel, (3) DC motor, (4 & 6) wheeled bases, (5) shaft, (7) sliding wheel, (8) universal joint, (9) soil moisture sensor.

In this study, the irrigation water treatments regarding two case studies under dry and wet soil conditions (from permanent wilting point to field capacity) were conducted for a period of 115 days and 110 days respectively. The irrigation water was precisely measured by a volumetric flask and applied directly onto the surface of the 36 equal cell-rectangles of the soil tank allowing high irrigation uniformity. On the first days (2/12/2013 to 19/12/2013) under dry soil conditions, the irrigation water was applied uniformly on the entire tank surface (0.25 l per each cell-rectangle) with an irrigation frequency of 9 liters every 4 days. This way 45 liters of water were initially irrigated. During the next days (20/12/2013 to 30/01/2014), non-uniform irrigation was applied in the soil tank according to the observations provided by the prototype electromagnetic sensor-based platform. In this case, only those cell-rectangles in which the observed soil moisture was lower than 10m$^3$m$^{-3}$ were irrigated. The purpose of the variable rate irrigation was to achieve distribution uniformity of soil moisture content in the soil tank around the desired limit of 10 m$^3$m$^{-3}$. This period of variable rate irrigation a total of 15.25 liters of water was consumed. The soil moisture content in tank was further increased after a period of one month (01/02/2014 to 28/02/2014) with distribution uniformity of irrigation water in all cell-rectangles (0.125 l per each rectangle). In this treatment the frequency of irrigation was 4.5 liters every 4 days, and was applied in a total 22.5 liters of water. The last time interval (01/03/2014 to 27/03/2014) during the dry soil conditions repeated the variable rate irrigation in the soil tank according to the indications provided by the electromagnetic sensor-based platform. In this case only those cell-rectangles in which the observed soil moisture content was lower than 16 m$^3$ m$^{-3}$ were irrigated. During this period of variable rate irrigation there was consumed a total of 27.25 liters of water.

The observations regarding wet soil conditions were conducted for a period of 16 weeks (28/3/2014 to 15/7/2014). 36 l of water were applied on the first 4 days (9 l for every irrigation session). The irrigation water was applied uniformly on the surface of each of the 36 equal cell-rectangles of the soil tank. In the next two months (01/04/2014 to 31/05/2014), the irrigation water was applied non-uniformly on the surface of the soil tank according to the observations provided by the prototype electromagnetic sensor platform. The aim of these irrigation treatments was to achieve distribution uniformity of soil moisture content in the soil tank around the field capacity. In this case study only those cell-rectangles in which the observed soil moisture content was lower than 27m$^3$m$^{-3}$ were irrigated. This period of variable rate irrigation a total of 32.5 liters of water for the first month (five sessions) and 35.5 liters of water for the second month (thirteen sessions) was consumed. On the other days (01/06/2014 to 15/07/2014), the change of the soil moisture content was only recorded without any irrigation treatment. The soil starts to lose moisture progressively while drying up from field capacity moisture content.

## 3 Results and Discussion

The distribution uniformity of the majority of irrigation systems is influenced by different factors (such as sprinkler operating pressure, sprinkler spacing, etc.). During this study the irrigation water treatments were conducted in the experimental soil tank, without crop cover, under controlled laboratory conditions, and with high application effort. The applied water cannot move laterally as surface flow due the elimination action of the wood frame. The applied water can move only vertically and then laterally due to capillary action of the soil in each cell-rectangle of the experimental tank.

The results of the uniformity coefficients (CU) of the applied water in different irrigation days in soil tank surface are shown in Fig. 2. The Christiansen's coefficient of uniformity (Christiansen, 1942) was used for calculating irrigation water uniformity. The 100 % of application rate tests of CU represent the treatments where the irrigation water was applied to all cell-rectangles evenly without application losses in order to achieve rapid and uniform distribution of soil moisture at the desired values. The low application rate tests (8.3 % to 68.3 %) of CU represent these treatments, in which the irrigation water was applied only in selected cell-rectangles according to the readings of the sensor-based platform in order to improve the general DU of soil moisture in the soil tank. Therefore, the lack of uniformity in the water application affects soil moisture distribution between cell-rectangles of the soil tank.

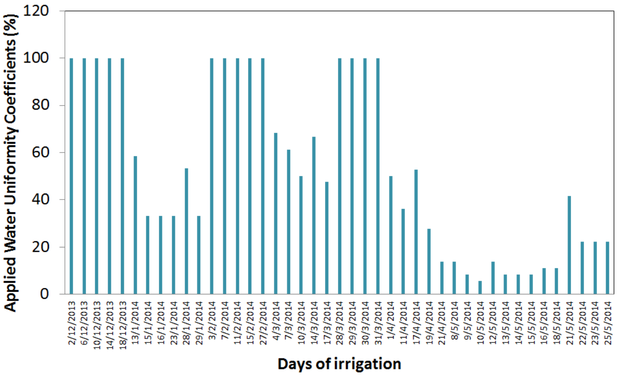

**Fig. 2.** Applied water uniformity coefficients during different irrigation days.

Fig. 3 shows the evolution of soil moisture distribution uniformity (DU) (Merriam and Keller, 1978) based on long-term data sets (2/12/2013 to 15/7/2014) that were collected during dry and wet soil conditions (from permanent wilting point to field capacity) and were calculated based on the average of the lowest quarter of soil moisture measurements (9 points) dividing by average of total soil moisture measurements (36 points) in the soil tank.

In permanent wilting point (before any irrigation water treatment) the resulting soil moisture DU was 80 %. On the twenty first days during which 100% of the application rate tests were conducted (with irrigation frequency 9 liters every 4 days), DU of soil moisture was found to be declining gradually from 80 % to 40.3 %. The low DU of soil moisture, after uniform rate irrigation treatments, was due to different water infiltration rate into 36 cell-rectangles of the soil tank that affects the moisture movement in soil. Infiltration rate is unmanageable and varies both in time and space. The investigation period from 20/12/2013 to 30/01/2014, under variable rate irrigation, indicated that the soil moisture DU increased rapidly on the first fifteen days and then followed a less upward trend. In this case, it only the cell-rectangles in which the observed soil moisture was lower than 10 m3 m-3 were irrigated, and 15.25 liters of water were consumed in total. In the last period, from 01/03/2014 to 27/03/2014 of the dry soil conditions, variable rate irrigation on the soil tank was repeated, but in this time it only the cell-rectangles in which the observed soil moisture was lower than 16 $m^3$ $m^{-3}$ were irrigated. However, in this period of variable rate irrigation 27.25 liters of water consumed in total and soil moisture DU remained nearly constant at 67 %. In general, the irrigation water treatments strongly affected DU of soil moisture during dry soil conditions. Constant DU can be achieved by using variable rate irrigation that is based on rigorous soil mapping techniques and schedule irrigation to specific points under the irrigator on a daily basis.

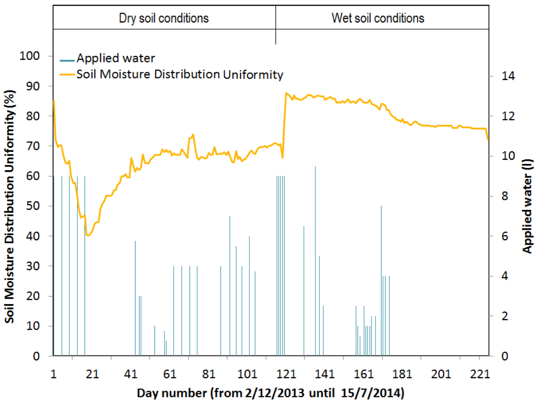

**Fig. 3.** Evolution of soil moisture distribution uniformity based on long-term data sets (2/12/2013 to 15/7/2014) that were collected during wet and dry conditions.

Then the DU of soil moisture in wet soil conditions near the field capacity was studied. On the first five days (28/03/2014 to 01/04/2014), the water was applied uniformly on the soil tank surface with irrigation frequency 9 liters per day. The resulting soil moisture DU was 87.7 % (significant increase). In the rest period of the wet soil conditions (01/04/2014 to 31/05/2014), only these cell-rectangles in which the observed soil moisture content was lower than 27 $m^3m^{-3}$ were irrigated. In this case the DU of soil moisture remains constant at 85.24 %, and 68 liters of water were consumed in total. During the last period of the wet soil conditions (01/06/2014 to 15/07/2014) without any irrigation water treatment, the resulting soil moisture DU was gradually reduced. According to the above results, DU of soil moisture was maintained at a high percentage and slightly affected by the irrigation treatments. In addition, DU exhibited lower sensitivity compared with DU in the case of dry soil conditions.

## 4 Conclusions

The results analysis indicates that, the irrigation water treatments strongly affect DU of soil moisture, which can be achieved by constantly using variable rate irrigation during dry soil conditions. On the other hand, DU of soil moisture maintains at high percentage and is slightly affected by the irrigation water treatments during wet soil conditions. In wet soil conditions the irrigation water is transformed and smoothed into less variable soil moisture values. Some regions of the experimental irrigated area, which received higher amounts of applied water, indicate higher soil water holding capacity than the others which received lower amounts of applied water. It is obvious that the spatial distribution of the moisture values depend more on intrinsic factors of the soil than on irrigation water distribution.

## References

1. Christiansen, J.E., 1942. Irrigation by Sprinkling. California Agriculture Experiment Station Bulletin, No. 670.
2. Gravalos, I.G., Moshou, D.E., Loutridis, S.J., Gialamas, T.A., Kateris, D.L., Tsiropoulos, Z.T., Xyradakis, P.I., 2012. Design of a pipeline sensor-based platform for soil water content monitoring. Biosyst. Eng. 113, 1–10.
3. Hu, R., Brauchler, R., Herold, M., Bayer, P., 2011. Hydraulic tomography analog outcrop study: combining travel time and steady shape inversion. J. Hydrol. 409, 350–362.
4. Merriam, J.L., Keller, J., 1978. Farm irrigation system evaluation: A guide for management. Dept. of Agricultural and Irrigation Engineering, Utah State Univ., Logan, Utah.
5. Moran, M.S., Peters-Lidard, C.D., Watts, J.M., McElroy, S., 2004. Estimating soil moisture at watershed scale with satellite-based radar and land surface models. Can. J. Remote Sens. 30, 805–826.
6. Muñoz-Carpena, R., 2004. Field devices for monitoring soil water. USA: Agricultural and Biological Engineering Department, Florida Cooperative Extension Service, Institute of Food and Agriculture Sciences, University of Florida.
7. Sentek Pty Ltd., 2007. Diviner 2000 User Guide Version 1.4. South Australia, Stepney.