FARM SCALE APPLICATIONS OF EMI AND FDR SENSORS FOR MEASURING AND MAPPING SOIL WATER CONTENT IN THE ROOT ZONE

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1. Introduction

Accurate measurements of soil water status across different spatial and temporal scales are a challenging task. Especially at intermediate spatial (0.1 - 10 ha) and temporal (minutes to days) scales, there is still a gap of knowledge related to the reliability of the soil water content (*SWC*) spatial measurements and their practical applicability for irrigation scheduling.

In this work, two *SWC* measurement techniques carried out with EM38 ground conductivity meter (Geonics Ltd. Canada) and with Diviner 2000 (Sentek Pty Ltd) probe, are associated in order to verify if the combined use of both the sensors can provide quick and suitable maps of soil water status in the root zone of an olive orchard.

Initially, the work allowed to identify the EM38 calibration equation to predict the fraction of transpirable soil water (*FTSW*). Then, the ordinary-Kriging procedure was used to map the spatial changes of *FTSW* indirectly estimated and based on the EM38 survey.

2. Case Study

The experiment was carried out in an olive orchard located in Sicily (latitude 37.6429°N, longitude 12.8471°W, elevation 123 m a.s.l.)
During dry season, a traditional drip system was used for irrigation, with four 8 l/h emitters per tree, placed in both sides of each plant, at one and two meters.
Spatial measurements of *SWC* were collected on a 1.25 Ha plot surface, in which 20 points were selected based on a regular 25m x 25m square grid (fig. 1a). In each point, six EM38 measurements (three in the horizontal and three in the vertical dipole orientation) were collected (fig. 1b), by placing the sensor at ground level and i) at the center of four trees (P1), in the middle between two trees along the row (P2) and below an emitter (P3).
One irrigation event distributed during two days was monitored in 2008. In particular, EM38 measurements were carried out immediately before and after an irrigation event, until the following watering, based on a weekly time-step.
Soil textural analysis was carried out on soil samples collected in the topsoil (0-0.3 m), at the same points where EM38 measurements were acquired. For these points, Figure 2 shows the soil classification according to the USDA textural triangle.
Due to the great variability of clay content, two sites (A and B) were selected for EM38 calibration. In each site, a FDR access tube, 1.2 m long, was installed (Figure 3). For both these sites soil textural analysis was carried out on disturbed soil samples collected every 0.15 m depth during the access tube installation. The calibration procedures took the whole irrigation season, during which 17 and 20 soil moisture profiles were acquired, respectively for site A and B.

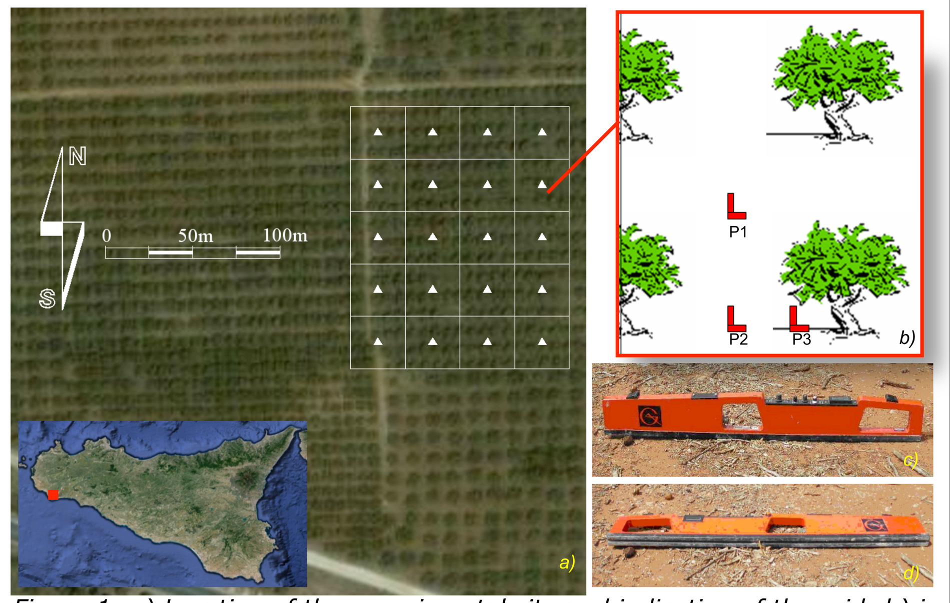

Figure 1- a) Location of the experimental site and indication of the grid; b) in each measurement point, at the center of each square, EM38 probe was placed in the vertical (c) and horizontal (d) orientation

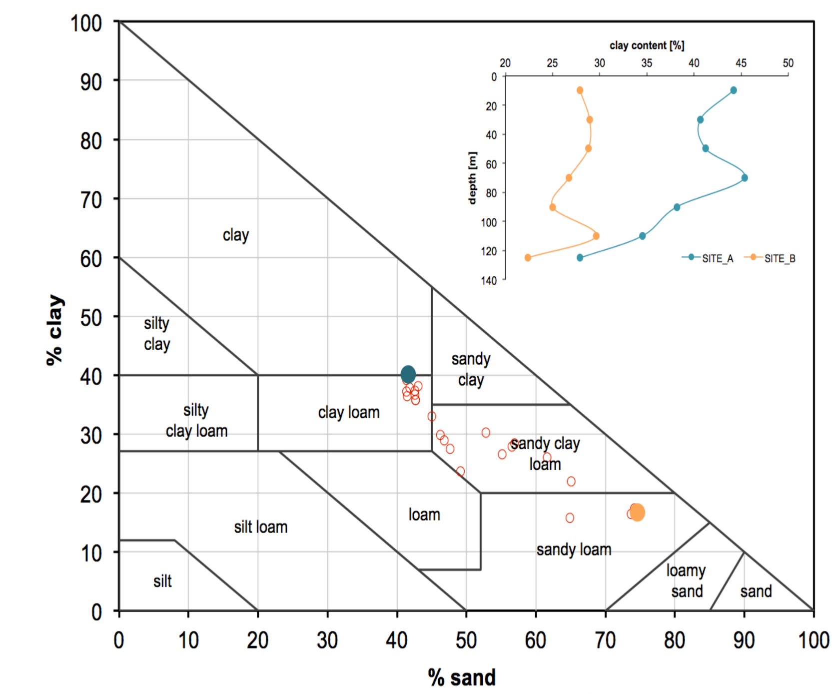

Figure 2 - USDA Soil texture triangle and texture of topsoil samples collected at the EM38 measurement points. For samples with maximum and minimum clay content, the vertical distribution of clay percentage is also shown.

Figure 3 – Access tube for Diviner 2000 probe used to monitor soil water status in the same sites selected for EM38 calibration

3. Methodology

EM38 ground conductivity meter measures the apparent bulk soil electrical conductivity (EC). The sensor induces a small current within the soil via a primary electromagnetic field from a transmitting coil and measures the resultant secondary field via a receiving coil. According to the instrument orientation (vertical or horizontal) the response is different: with vertical dipole it is possible to explore a deeper soil layer than with the horizontal dipole, whose response is strongly influenced by the upper soil layers (Figure 4). According to Cook and Walker (1992) a linear combinations of vertical and horizontal readings can be used to assess a single depth response function that better matches the portion of the investigated soil profile. By combining the two values, the total EC_t is obtained:

$$EC_t = 0.77EC_V + 0.23EC_H \qquad \text{(eq. 1)}$$

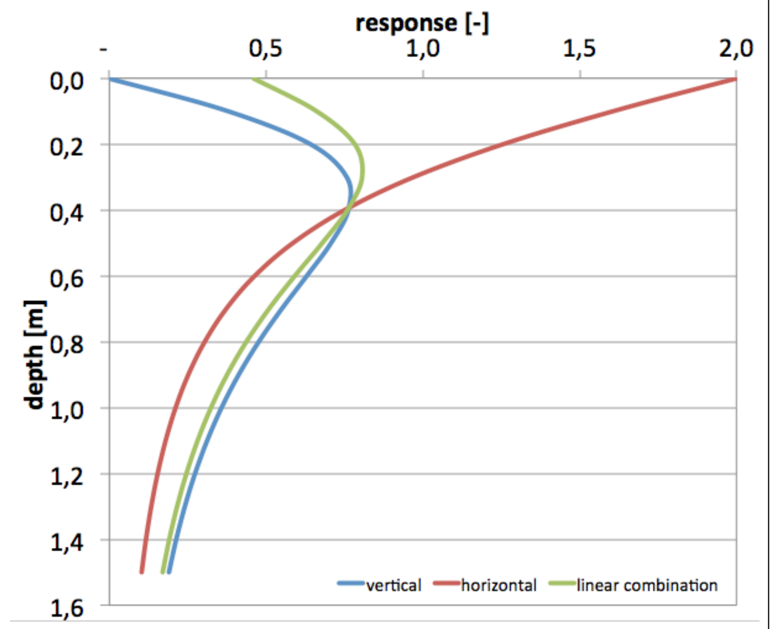

Figure 4. Depth response functions for EM38 used in vertical and horizontal dipole orientation. The linear combination of both measurements (eq.1, EC_v/EC_t=0.77; EC_h/EC_t=0.23) is shown for comparison (Cook and Walker, 1992)

The Diviner 2000 probe (Sentek Pty. Ltd., South Australia) allows determining soil water content by measuring the sensor scaled frequency, *SF*, once it is known the *SWC*=f*(SF)* calibration equation. The relationship obtained by Provenzano et al. (2016) was used in order to ensure accurate *SWC* estimations for the investigated site.
Following the approach of Lacape et al. (1998) in each site, the total transpirable soil water (*TTSW*) can be estimated as the sum of the differences, over the explored soil depth (1.2 m), between soil water content at field capacity (SWC_{fc}) and minimum soil water content (SWC_{min}):

$$TTSW = \sum_{0}^{1.2}(SWC_{fc} - SWC_{min}) \qquad \text{(eq. 2)}$$

These two soil water contents were estimated from measurements acquired after a strong rainfall event and at the end of irrigation season. In particular, SWC_{fc} resulted equal to 33% and 27%, whereas minimum soil water content, was equal to 13% and 11%, respectively for site A and B.
On the other hand, available soil water at a given time (*ASW*) was calculated as the sum of the differences, over the explored soil depth, between the actual, SWC_d, and minimum, SWC_{min}, soil water content:

$$ASW = \sum_{0}^{1.2}(SWC_d - SWC_{min}) \qquad \text{(eq. 3)}$$

The fraction of transpirable soil water (*FTSW*) was finally evaluated as the ratio of *ASW* to *TTSW*.
Paired readings of EC_V and EC_H were acquired around each Diviner 2000 access tube approximately weekly so to explore, in both sites, quite different soil water status. Each EC_V and EC_H reading was weighted in order to obtain a single value of EC_t as computed in eq.1.
EC_t was regressed against the estimated *FTSW* in order to dispose a field-specific calibration, valid for EM38 soil water monitoring technique.

4. Results and Discussion

A variety of soil moisture conditions were considered for calibration, as can be observed from Figure 5, in which profiles of maximum, mean and minimum *SWC* are shown. Compared to site B, a more marked *SWC* variations was observed in site A, due to the higher clay content.

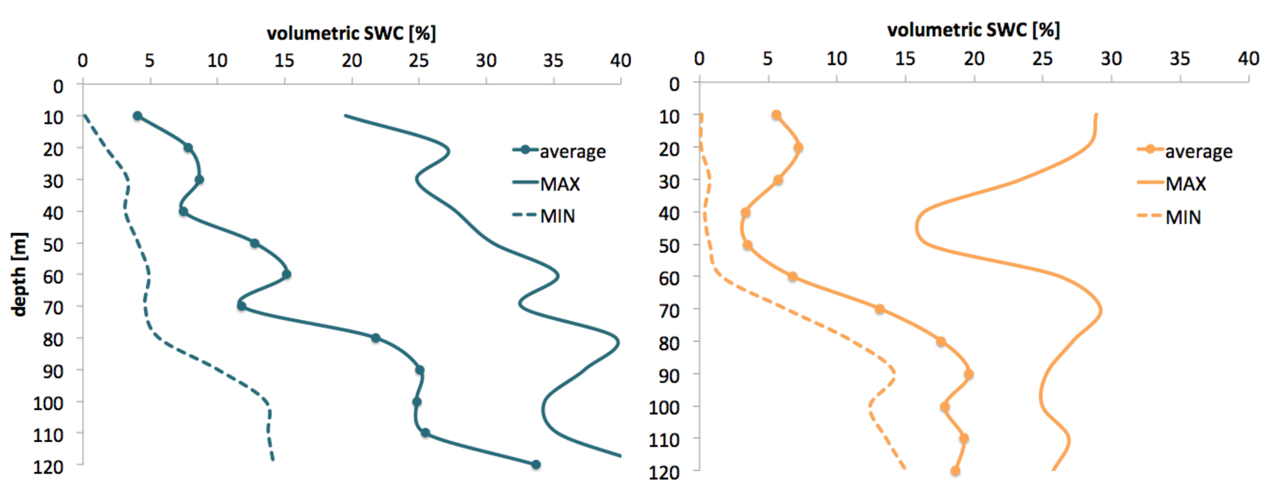

Fig- 5 – Example of volumetric SWC profiles that were associated to paired EM38 readings for calibration purposes

The variations of soil water content along the soil profile also ensured that the collected dataset encompassed most of the soil water status occurring during the investigated irrigation season.

A strong correlation was found between EC_t measured with EM38 and the corresponding *FTSW* obtained with Diviner 2000 measurements (Figure 6). Negligible differences between the regression models were observed for sites A and B. A similar result was obtained by Huth and Poulton (2007), who evidenced that the term SWC_{min}, used to evaluate *FTSW*, account for the conductivity of the solid phase and consequently reduces the effects of the different clay content characterizing the two sites. Moreover, the term (SWC_d-SWC_{min}) takes into account the effect of both the liquid phase conductivity and the soil pore space.
A single equation was then obtained for both sites and used to convert the spatially distributed EC_t in fraction of transpirable soil water (*FTSW*).

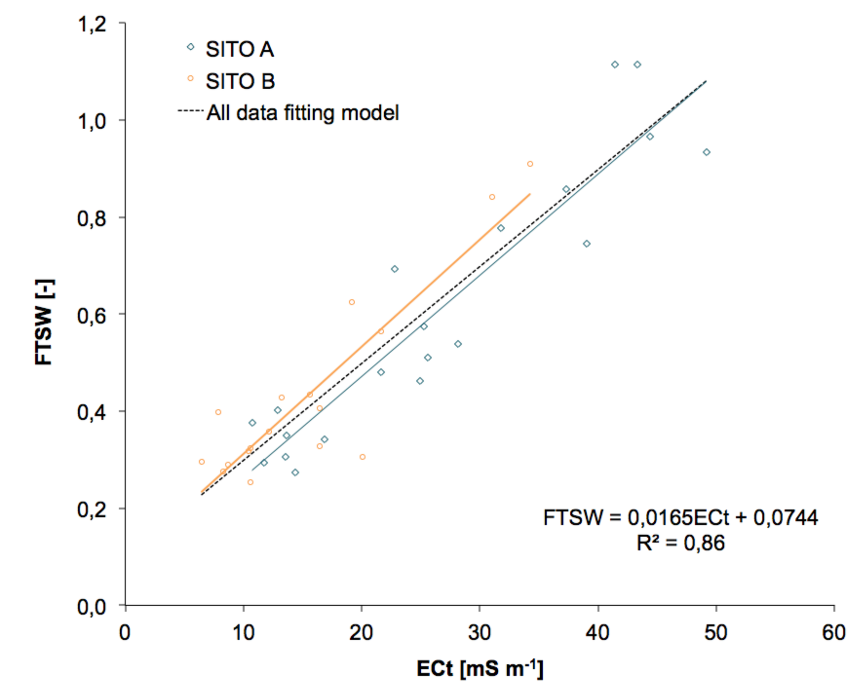

Figure 6. EM38 readings (EC_t) calibrated against fraction transpirable soil water (FTSW) for site A and B. The all data fitting equation is also shown

Figure 7 shows that the temporal dynamic of EC_t is sensible to changes of SWC. In fact, EC_t values increase after a wetting event and decrease during soil drying. Even the standard deviation associated to EC_t values is higher after irrigation and lower when the soil is dry. The high standard deviation recognized after irrigation is due to the localized irrigation system. In fact, EM38 readings collected at the center of four tree (P1), does not detect any change in soil water content, contrarily to the readings collected in the proximity of the emitter (P2 and P3).
Figure 8 shows the spatial distribution of *FTSW* indirectly estimated according to the EM38 survey. As can be noticed, more structured patterns occur after wetting events, as a consequence of subsurface flow, soil evaporation and root water uptake processes.

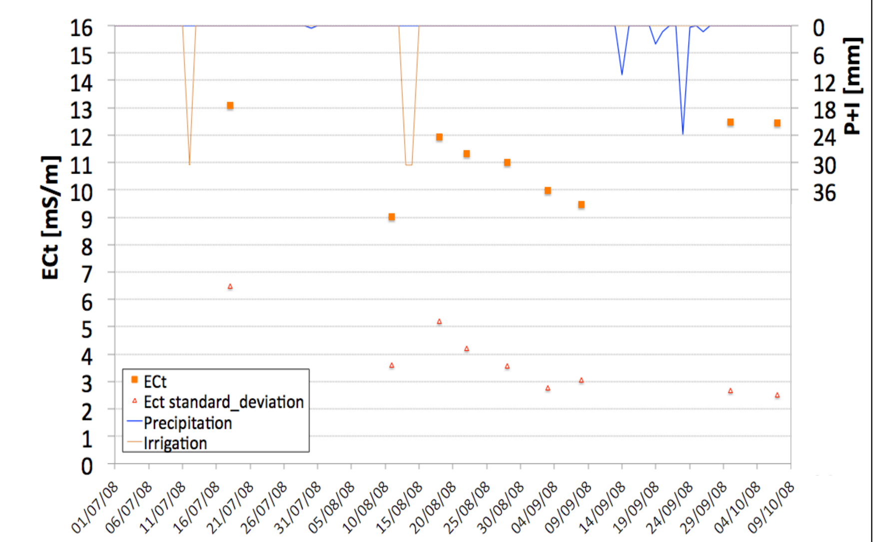

Figure 7. Temporal dynamic of EC_t values and the corresponding standard deviation during irrigation season. Irrigation and precipitation events are also shown.

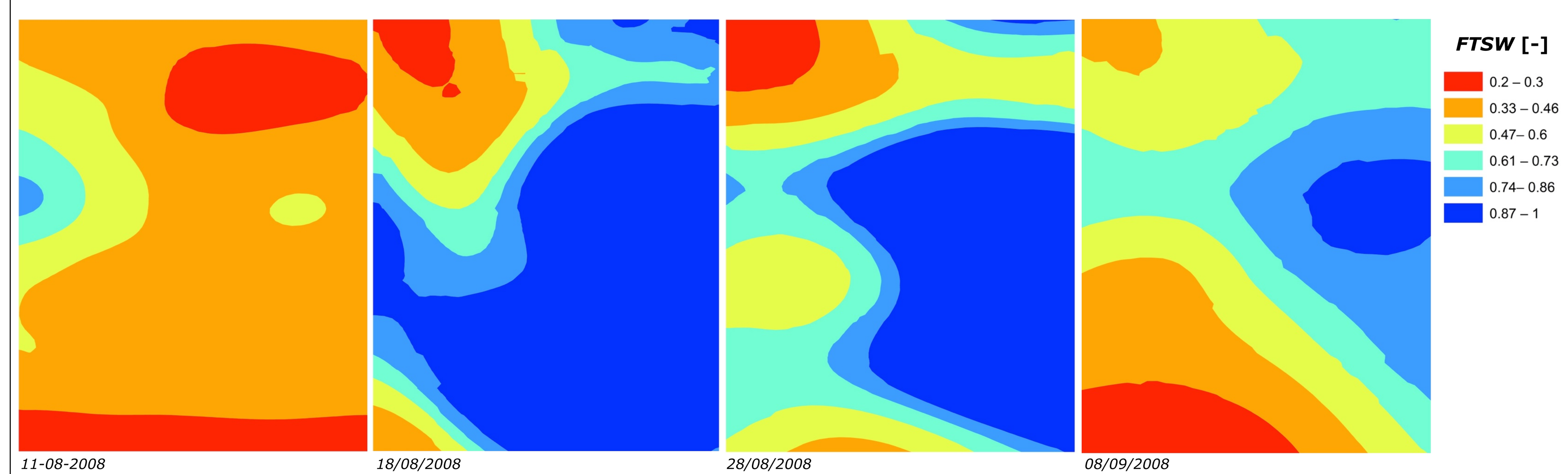

Figure 9. Maps of the fraction of transpirable soil water (FTSW), in some days before and after the irrigation event of 13-14 Aug 2008

5. Conclusion

A strong linear relationship (R^2=0.86) was found between the fraction of transpirable soil water (*FTSW*), integrated to a depth of 1.2 m, and the total bulk electrical conductivity (EC_t), obtained by combining EM38 readings at the soil surface, in the vertical and horizontal orientation.
Maps of *FTSW* were obtained at different time steps. More structured patterns occur after an irrigation event, indicating the presence of subsurface flow, soil evaporation and root water uptake processes. Future research will be aimed to develop the proposed approach, in order to map the uncertainty of *FTSW* predictions in sparse crops under drip irrigation systems.

6. References

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