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1st International Congress on Biosystems Engineering 2019 **ARAŞTIRMA MAKALESİ/RESEARCH ARTICLE**

Monitoring soil electrical conductivity as an agricultural management tool in drip-irrigated citrus field via EM38

Damla sulama ile sulanan narenciye bahçesinde EM38 aleti kullanalarak toprak elektriksel iletkenliğinin izlenmesi

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ÖZET / ABSTRACT

Aims: Soil salinity continues to be one of the vital environmental problems affecting both crop yields and soil quality. Therefore, monitoring spatial and temporal soil salinity at the field level is highly crucial. Electromagnetic induction (EM) technique is a widely used tool for mapping of measuring the apparent bulk salinity (ECa) of a soil-water continuum. Therefore, the objective of this study was to investigate the spatiotemporal variability of soil salinity in a drip irrigated citrus field located in Adana, Turkey.
Methods and Results: To monitor soil salinity electromagnetic induction device, EM38 was used. Both horizontal (EM_h) and the vertical (EM_v) dipole orientations of EM38 was utilized to assess the salinity. In order to convert EC_a lectures to the standard soil salinity levels of ECe, calibration equations in turn for EC_{ah} and EC_{av} were developed for the site by following conventional soil sampling and salinity measurement. The calibration models were satisfactory with the correlations over 0.70. EM38 lectures were done each month, from April to September. After converting EC_{ah} and EC_{av} readings by EM38 to the standard soil salinity values of EC_{ev} and EC_{eh}, respectively, interpretation of the standard soil salinity data reflected that average salinity increased about 19 and 21% in the soil profile with the depth of 1 and 2 m soil, respectively, in an irrigation season.
Conclusions: The salinity was significantly increased at the end of irrigation season. Additionally, a concrete-lined irrigation channel located the very close to the field caused an increase in soil salinity and farther from channel the soil salinity values were decreasing. Thus, the irrigation water penetration could be occurred from channel to the field.
Significance and Impact of the Study: Consequently, the monitoring approach is able to be adapted successfully in practice so that the soil salinity could be quantified easily and rapidly.

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INTRODUCTION

Irrigation is necessary in arid and semi-arid agricultural production zones to provide the global food safety. However, irrigation induced soil salinity could be a serious concern within a span of several years of irrigation. Thus, salt accumulation in the root zone limits the productivity of field crops, pasture plants or trees, and provokes desertification in arid climates. Rapid, reliable and cost-effective mapping of the soil salinity is received a considerable interest in intensive agricultural areas where the soil salinity is restrictive. Precise field evaluation of salinity via soil sampling is highly time consuming and costly (Slavich and Read, 1984). Contrarily, electromagnetic (EM) bulk salinity assessment is a noninvasively method that permits lectures of apparent soil electrical conductivity (ECa) by inducing an electrical current in the soil (McNeill, 1980). The induced electromagnetic field when transferred into an output voltage relates linearly to depth-weighted soil apparent salinity (Rhoades, 1992). EM induction technique is more secured than other monitoring methods due to not requirement of a radioactive source (Padhi and Misra, 2011). Therefore, the EM38 is portable equipment developed to take in field lectures of apparent soil conductivity promptly and accurately (Çetin et al., 2012). The device is placed on the ground horizontally (ECa_h) and vertically (ECa_v) which reflects the soil profile with the depth of 1 and 2 m soil, respectively. Furthermore, data collected with the EM38 instrument are essentially known as apparent soil salinity, ECa, which can be converted to standard soil extract salinity (ECe) with proper calibration (Çetin et al., 2012).

In situ determination of the ECa via EM38 has attracted significant attention of the precision agriculture community (Corwin and Lesch, 2005; Padhi and Misra, 2011). In turn, Çetin et al. (2012) and Kaman et al. (2013) successfully used the EM38 device in soil salinity surveys in large-scale irrigation schemes, and they proved that the EM38 provided reliable enough estimates of soil salinity without intensive soil sampling. In literature, there are some cases that EM38 device has been used for other purposes. For instance, Kachanoski et al. (1988, 1990) found that spatial variation in soil water content within the top 0.5 and 1.7 m to be highly correlated with the spatial variation in bulk soil electrical conductivity monitored with EM38 device. Thus, also this instrument could be helpful to potential measurement for predicting variation in crop production caused by soil water change (Heermann et al., 2000). In this context, the method has been increasingly applied in precision agriculture and has been widely used for different purposes such as assessing soil salinity (Herrero et al., 2003; Bennett and George, 1995; Triandafilis et al., 2000; Bennett et al., 2000; McLead et al., 2010; Çetin et al., 2012), salt leaching (McLead et al., 2010), soil sodicity (Amezketa, 2007; Nelson et al., 2002), soil acidity (Dunn and Beecher, 2007), spatial variation of soil moisture (Huth and Poulton, 2007), soil texture (Hedley et al., 2004), depth to clay pan (Sudduth and Kitchen, 1993; Sudduth et al., 1995; Jung et al., 2006), crop yield responses to salinity (Bercero and Aragues, 1996; Aragues et al., 1999) and in applications to upgrade soil map (Vitharana et al., 2008). However, locally conducted trials are required to improve the application of this technique in specific regions and cultural systems. In turn, deriving calibration equation for the study site is a prerequisite in order to utilize the EM38 lectures.

Staple objectives of the work were three-fold: *(a)* to study functional relationship between ECa and ECe and *(2)* to show whether mapping and monitoring of soil salinity are within the bounds of possibility through utilizing EM38 device in both vertical and horizontal dipole modes, and *(3)* to reflect temporal changes in the soil salinity in a Citrus orchard in an irrigation season.

MATERIALS and METHODS

Experimental Area

This study was carried out in a drip irrigated citrus orchard plantation −covering 30 da area in Karayusuflu village− in the Lower Seyhan Plain. Study area is geographically located within latitudes of 36° 52' 08"−36°52'11" N and longitudes of 35°12'58"−35°13'01" E in the south-west direction of the city Adana (Figure 1) with an altitude of 10 m above mean sea level. August is the hottest month with long-years average temperature of 28.7°C, and January is the coolest month with the 9.5 °C temperature. Annual average precipitation is about 647 mm. The area has Mediterranean climate characteristics with cool and rainy winters, hot and dry summers.

In the experimental site, the irrigation season generally starts in April, and ends in October. Irrigation water used in the field is obtained through the well with a depth of 200 m. Until July, the orchard is irrigated four times a month, and then, 8 times a month. Each irrigation application lasts for 5 hours. Drip irrigation system consisted of 2 l h^{-1} flow rate drippers and two laterals in each citrus row. Furthermore, according to the USSL irrigation water classification, irrigation water was classified as C2S1. During the irrigation season in 2006, total monthly rainfall in April, May and June were recorded as 9.3, 19.8, and 4.5 mm, respectively.

Çanakçı soil series, consisted of largely alluvial deposits of the delta plain, is dominant in the study field. The low permeability of the soils due to very heavy clay texture is the major constraint to farming practices. Soil lime content is about 20% and is considered rather high. Soil pH ranges from 7.4 to 7.6 with high exchangeable Na percentage.

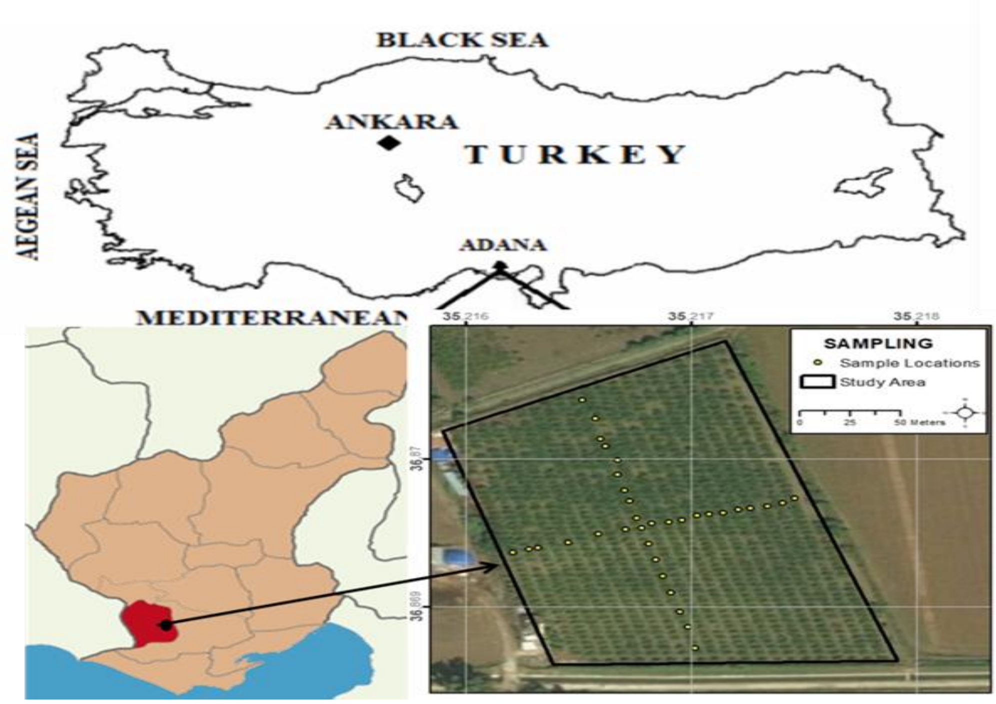

Figure 1. The coordinates of the soil samplings

Soil Salinity Measurements

Soil ECa values were measured at 34 sampling point with EM38 device by orienting it in a horizontal (ECa_h) and vertical (ECa_v) dipole modes. To this end, six sets of lectures were done on two transects in the field −from April to August (Figure 1). As a precaution, any metal objects that may influence the electromagnetic field of the EM38 were removed during the measurement process. Ten locations out of 34 points −covering both the entire citrus orchard and the full range of EM38 readings− were selected for conventional soil sampling with auger. Soil sampling was done in April and August to derive a representative calibration equation of EM38. For this purpose, soil samples from 0–30, 30–60, and 60–90 cm layers of the soil profile were collected directly from beneath the EM38 reading locations. Soil moisture increased with depth at all sampling sites due to the influence of shallow groundwater table. Both the ECa reading locations as well as soil sampling sites were geo-referenced by using a GPS equipment as UTM.

Collected soil samples were air-dried, grounded and sieved to pass through a 2 mm screen. Saturation soil pastes were prepared using 100 g sub-samples, kept in the laboratory for 12 hours of equilibrium time, and the saturation extracts were taken to make standard electrical conductivity (ECe) measurements of the soil via following the procedure described by USSL (1954). Average ECe values in the profile were calculated for EM38 calibration process.

Deriving Calibration Equation of The EM38 Device

The EM38 readings from 10 soil sampling sites including ECa_h and ECa_v were separately calibrated against the mean ECe values, and the best-fit models for horizontal and vertical lectures were selected by curve estimation procedures as explained in Diaz & Herrero (1992). To this aim, mean ECe values for a specified depth served as a dependent variable and apparent conductivities measured (ECa_h and ECa_v) at the locations where soil samples were taken as independent variable −$ECe=f(ECa_h)$ for 0.0-1.0 m soil depth and $ECe=f(ECa_v)$ for 0.0-2.0 m soil profile. All the candidate models including linear, curvilinear, exponential and power curves were tested to get representative calibration curve for horizontal and vertical EM38 measurements. To facilitate the selection of the best fitting model, the association between the two variables was first examined on scattered graphs. The model with all of the parameters significantly different from zero ($P < 0.01$ level) and with the smallest mean square error (MSE) was selected as the best representative calibration model.

Spatial Variability of Soil Salinity

Kriging is a stochastic optimal interpolation method, frequently used for interpolation of both weather and soil variables. In recent decades, *kriging* has become a very popular interpolation method, due to its advantageous properties; each estimate is supplied with confidence information in which the quantified uncertainty increases with the distance from the observation points; an estimated spatial picture of a variable links up continuously with the observations at the observation points. It is a statistical method of which statistical tests (variances of the parameter estimates) can be derived. Kriging provides a measure of uncertainty of the estimated surface; the technique is powerful and can be easily programmed. The input data at known locations are used for the derivation of semi-variogram −representing usually an irregularly spaced sample of points. The basis of the *kriging technique* is the rate at which the variance between points changes over the space. This is expressed through the semi-variogram which shows how the average difference between values at points changes with the distance between the points. The spatial distribution patterns of soil salinity were studied by examining the ECe maps produced through using *kriging interpolation* (Royle et al., 1981) technique. The contour maps were produced for the ECe_h and ECe_v values −estimated from the ECa-H and ECa-V readings, respectively.

RESULTS and DISCUSSION

As explained in detail in the section of materials, ECa lectures were done and soil samples were manually collected from the 10 sampling points. Table 1 reflects some statistics of ECa_h and ECa_v, and the average soil salinities at 0-30, 30-60, and 60-90 cm soil depths. Electrical conductivity values of the soil paste extract, i.e. ECe, decreased with increasing soil depth, indicating that the vertical variability and level of salinity in the deeper horizons were low. This kind of salinity development in irrigated areas is an indication of inverted electrical conductivity, i.e. salinity, profiles. Additionally, inverted salinity profile might be the cause drip irrigation practice. Furthermore, this could be the effect of soil texture that upper horizons have higher soil water holding capacity. Moreover, it could be very high evapotranspiration at the upper horizons or soil surface results in accumulation of salt in the system as mentioned by Çullu et al. (2002). The coefficient of variation of ECa_h, ECa_v and ECe were highly acceptable ($CV \ll 30\%$), confirming the homogeneity of soil salinity distribution in the study area. According to the average values of the EM38, ECa_v and ECa_h were increased significantly as well as 19% and 18%, respectively.

The point patterns on the graphs for EC_{ah} vs. EC_{av} readings at the EM38 monitoring sites (n=34) showed that the relationship between variables were in the linear form with the determination coefficient R^2>95%, although some dispersion was evident in the EM38 lectures (Figure 2). Herrero et al. (2003) and Amezketa (2007) concluded that both EC_{ah} and EC_{av} readings were similar (i.e. slopes are almost 1.00 and intercepts close to 0.00). In this study, in most cases EC_{av} readings were slightly higher than EC_{ah} readings as mentioned by Kaman et al. (2013). The reason for this could be the higher water table level that affects vertical readings. At the end of the season EM38 lectures showed higher salinity values than soil sampling results. This could be explained by the increased soil water content as mentioned by Korsaeth (2005). Therefore, it is of great importance that ECa readings should be done when the soil moisture is about at the field capacity level. In this study, ECa readings were, in turn, done two days after irrigations.

Table 1. Descriptive statistics of apparent soil salinity readings at horizontal (ECa_h) and vertical-dipole position (ECa_v) readings with EM38 at salinity monitoring sites and ECe values at manual soil sampling points. Salinity values are in the unit of µmhos cm^{-1}

Statistics	Sampling points 0-30		Sampling Points 30-60		Sampling Points 60-90		EM38 Readings ECa_v		EM38 Readings ECa_h	
	Start	End	Start	End	Start	End	Start	End	Start	End
Mean	490	505	444	457	420	446	495	585	466	548
Median	478	485	440	452	423	428	467	537	461	543
Minimum	460	463	420	429	372	396	436	447	449	474
Maximum	560	574	480	494	470	571	668	887	500	686
Std. deviation	31	40	22	21	35	55	62	120	15	55
Skewness	1.56	0.88	0.64	0.65	0.11	1.70	0.99	0.65	0.57	0.79
Kurtosis	2.32	-1.01	-0.79	-0.16	-1.14	3.19	0.14	-0.55	-0.82	0.04
CV%	6	8	5	5	8	12	13	20	3	10

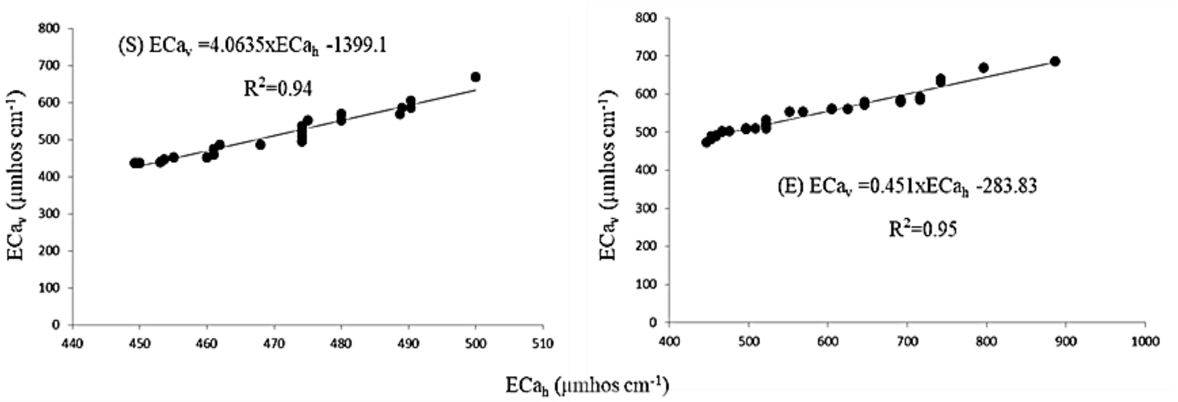

Figure 2. Linear relationships between horizontal- (ECa_h) and vertical- (ECa_v) dipole position apparent soil salinity lectures of electromagnetic induction meter (EM38): (S) at starting (n=34), (E) at the ending (n=34)

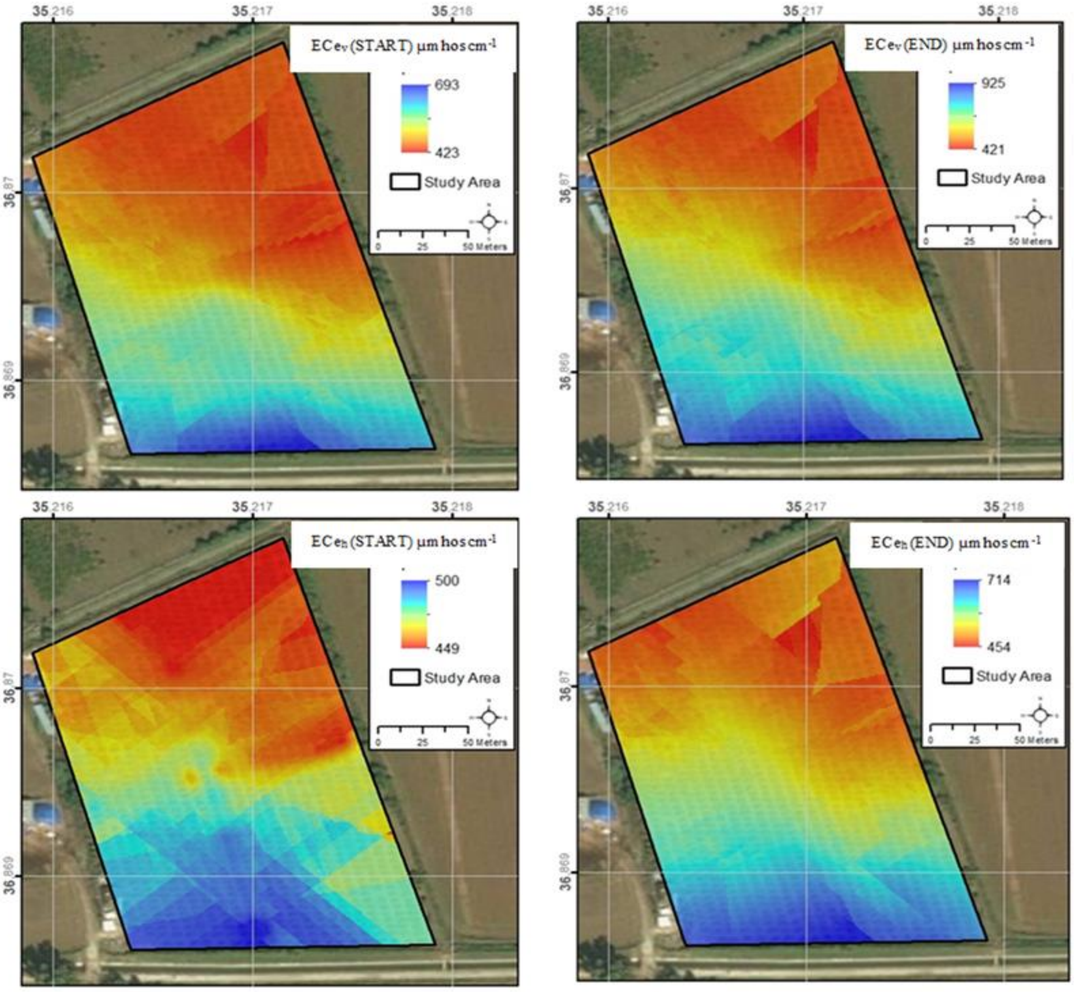

Figure 3. Spatial variability of soil salinity in the 0-1 m (ECe_h) and 0-2 m (ECe_v) soil depth at the beginning and at the end of irrigation season

As for the calibration equations, either ECa_h or ECa_V measurement at the 10 soil sampling points was preferred as a covariate to obtain calibration equations for ECe. Acceptable polynomial correlations were obtained between the average ECe values obtained from the soil depths of 0-30 to 0-90 cm. The coefficient of determination (R^2) for the calibration equations of ECa_h and ECa_v were found statistically significant ($P<0.001$). Furthermore, R^2 was about 0.63 for the ECa_v lectures in the 0-90 cm soil profile and 0.81 for the ECa_h lectures in the 0-60 cm soil profile. It is important to highlight that calibration results were found in good agreement with the results given by Kaman et al. (2013). Furthermore, Herrero et al. (2003) reflected strong linear relationships between average ECe values (obtained from 0-25 to 0-150 cm soil depths) and ECa_v and ECa_h lectures.

In this study, the calibration equations were used to convert ECa lectures to standard ECe readings in order to make logical and/or reasonable interpretations. Then, soil salinity maps were generated for the study site in order to delineate spatial character of soil salinity. Based on the soil salinity maps (Figure 3), it is clearly visible that salinity levels in the soil increased with time during the irrigation season. A qualitative comparison of these maps suggests that there may have been a pronounced rise in soil salinity in the north to south section of this field. Vertical and horizontal salinity readings showed that salinity was higher in the southern parts of the field where the irrigation canal was located. Furthermore, the salinity levels were decreasing in the vicinity of drainage canal located at south of the field, indicating the proper functioning of the drain age canal. Thus, the water intrusion from irrigation canal influenced the salinity degree of the citrus field although the canal is concrete-lined and water quality is good. Even so, the drainage canal works well as it was expected. ECe_h values −observed in 0-1 m soil layer− ranged between 400-500 µmhos cm^{-1} at starting of the irrigation season and reached up to 715 µmhos cm^{-1} at the end of the season. Likewise, ECe_v results −observed in 0-2 m soil layer− reflects that at the start of the season the salinity ranges between 400-690 µmhos cm^{-1} and reached up to 925 µmhos cm^{-1} in some parts of the field at the end of the season.

CONCLUSIONS

This case study proved the applicability of EM38 device in the soil salinity survey works in a semi-arid part of Mediterranean region of Turkey. The application of soil sampling and site-specific lectures of electromagnetic induction equipment (type EM38), relations between soil salinity and electromagnetic induction measurements reflects an acceptable rapid and easy way to use the EM38 device in the agricultural areas to determine salinity. The outcomes showed that the EM38 readings were quite higher than the manually sampled salinity data, which could be related with the increased soil water content. The horizontal EM38 lectures were lower than the vertical ones, indicating inverted salinity profile in the study site. Although the salinity levels are rather low compared with the threshold value for the citrus, normal salinity profile are desirable for the sustainability of orchard field. The salinity was significantly increased at the end of irrigation season. Therefore, leaching is necessary by winter precipitation or irrigation applications. Water intrusion or leakage from irrigation canal to the field may accelerate salinity development in the agricultural area. However, proper drainage canals are beneficial for managing soil salinity as the case in this study.

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DECLARATION OF CONFLICTING INTERESTS

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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