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SPATIAL ASSESSMENT OF SOIL SALINITY BY ELECTROMAGNETIC INDUCTION SURVEY

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Abstract

Salinization occurs in natural conditions as a result of a complex of factors such as climate, topography, and hydrogeology. Salinity principally occurs in sub-humid to arid regions but secondary salinization is a consequence of direct human activities it extends by the day. In the field, soil salinity is deduced from apparent electrical conductivity (ECa) by using a range of devices. Although a number of proximal sensors have recently been used worldwide to simplify fieldwork, few studies using new technologies have been addressed in Romania. The objective of this study was to assess the spatial variability of the apparent electrical conductivity of saline soils using a DUALEM instrument in Valea Sărată (Cluj). Spatial variability maps were generated by using of a geostatistical method. Significantly higher ECa was detected in poorly drained areas close to water channels (ECa above 1000 mS/m), while lower and less variable ECa values were recorded on the side slopes (ECa<200 mS/m). These areas correspond with eutric salic regosol identified on upper lands. The map of ECa measurements at surface show a higher variability of salinity then at depth at which the ground water disolved the salts. The instrument proved to be more efficient compared with traditional methods, regarding soil salinity mapping and delineating the soil boundaries.

Keywords: DualEM sensor, electromagnetic conductivity, salinization, soil electrical conductivity, spatial variability

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1. Introduction

Over the years for the emergence and expansion of soil degradation processes through salinization has represented an alarm for the international scientific community but in Europe salinization was not considered as important as in areas such as the Australian continent, which have long suffered from its consequences. According to the Technical Report of European Commission's JRC (Joint Research Center) on Degraded Soil Status in Europe, it is estimated that around 18.3 million ha are affected by soil salinization in Europe (JRC-ESDAC 2016). Spain, Hungary, Slovakia, Greece, Austria, Bulgaria, Bosnia, Serbia, Italy, France and Romania are among the most affected countries by naturally induced salinization are (Teşileanu and Fedorca, 2015). In Romania, halomorphic soils (saline and alkali), together with all zonal and intrasonal soils affected by salinization or alkalization account to almost 609,000 ha (Fig. 1). Majority of affected areas are found in the Western Plain - 175,000 ha, the Romanian Plain and the Danube Meadow - 13,000 ha. Other areas are Jijia, Bahlui and the Moldavian Plateau - 55,000 ha, the Black Sea coast and the Danube Delta - 37,000 ha, as well as the Transylvania Plateau, with 5,000 ha. In the County of Cluj, 570 ha of salty soils represent (OSPA Cluj, 2014). Soil salinization consists of modified parameters in saline, sodic and alkaline soils (van Beek and Tóth, 2012), defined as high salt concentration, high sodium cation (Na^+) concentration, and, respectively, high pH, often due to high CO_3 concentration in the soil. Soil salinization also relates to the alteration or even

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disruption of the natural biological, biochemical, hydrological and erosional parameters (Berendse et al., 2015; Decock et al., 2015; Keesstra et al., 2012; Smith et al., 2015). It is a major cause of yield reduction, regardless of its source (primary salinization or secondary salinization). Actually, the chances of plant survival are limited by the concentration of salts due to physiological processes induced by salinization in plants (Zhang et. al., 1999).

Primary salinization refers to accumulation of salts as a result of natural processes, mainly including physical or chemical weathering and transport from parent material, geological deposits or groundwater.Human activities, through the use of salt-rich irrigation water, can cause artificially induced salinization, the most affected countries being Italy, Spain, Hungary, Greece, Cyprus, Portugal, France (West coast), the Dalmatian coast of the Balkans, Slovakia and Romania, but also some North Europe countries, such as Denmark, Poland, Latvia, and Estonia (RECARE Project, 2015). Soil salinity can be measured by a range of different methods, according with the purpose of the indicator. Soil salinity is usually assessed in the laboratory by determining either the total soluble salts (TSS) or by determining the electrical conductivity of the saturation extract (ECe) or of a soil solution (ECw). In the field, soil salinity is usually deduct as apparent electrical conductivity (ECa) by using a range of devices.

Standard method for soil salinity measurement is based on a laboratory method (EC of the soil saturation extract at 25°C) that is a cumbersome giving rise to limitations in data-intensive works (Visconti and de Paz, 2016). Saturation extract is a labour-intensive and soil-destructive work. Different new techniques have been developed to measure the soil ECa, based on i) potential drop or electrical resistivity (ER), ii) electromagnetic induction (EMI), and iii) time (TDR), amplitude (ADR), or frequency (FDR) *domain* reflectometry. Electromagnetic induction (EMI) technique has received considerable attention over the last ~30 years allowing the rapid and relatively inexpensive collection of large spatially-related data sets (Brevik, 2002). Since then, an increasing number of different EMI sensors have been developed in response to users' needs. The non-contact or non-invasive soil sensors based on EMI are presently the most commonly used for sensing techniques (Simpson et al., 2009). The benefits provided by EMI investigations are: i) large amount of georeferenced data rapidly and inexpensively collected, ii) a more thorough characterization of the spatial variations in soil properties than traditional sampling techniques, iii) more effective assessment of diffuse soil boundaries to identify areas of dissimilar soils within mapped soil units. According to Doolittle and Brevik (2014), EMI techniques do have some limitations: the results are site-specific and may vary depending on the complex interactions among multiple and different soil properties. However, EMI techniques are used increasingly to investigate the spatial variability of soil properties, especially salinity, at field and landscape scales. As some researchers emphasized (James et al., 2003; Jaynes, 1995, 1996; Shaner et al., 2008), ECa maps have the potential to provide higher levels of resolution and also in the characterization and delineation of mapping units.

ECa proved to be an important agricultural tool that provides spatial information for precision agriculture applications (Corwin and Lesch, 2005a). ECa is influenced by a combination of physico-chemical properties such as soluble salts, saturation percentage, organic matter, clay content, soil water content, soil temperature and bulk density. Consequently, measurements of ECa have been used to map the spatial variation of several soil properties: soil salinity, organic matter content, clay content or depth to clay-rich layers, soil water content. Electrical conductivity (EC) is the ability of a material to transmit (conduct) electrical current and is commonly expressed in units of milliSiemens per meter (mS/m).

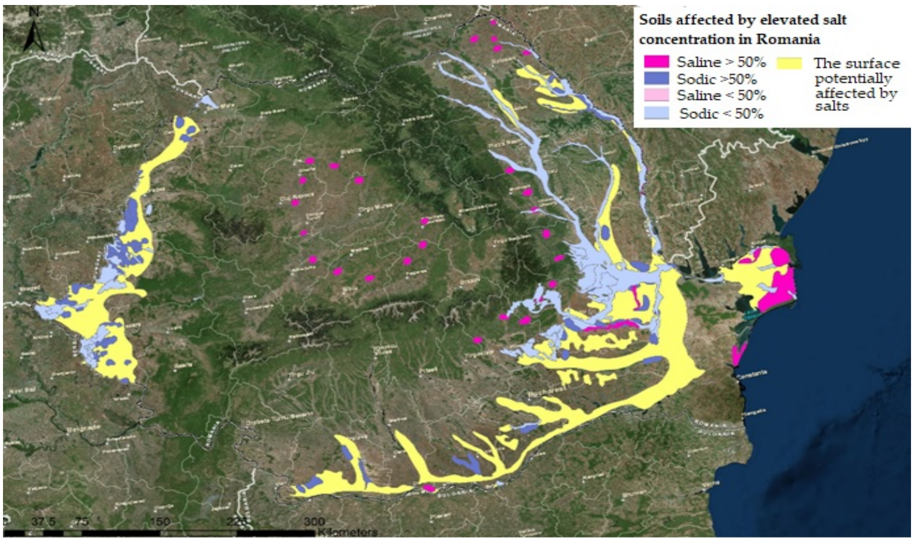

Fig. 1. Geographical location of soils affected by salinization in Romania (Toth et al., 2008)

The use of geo-referenced measurements of ECa as a substitute of soil spatial variability is based on the conception that when ECa correlates with a soil property, then spatial ECa information can be used to detect sites that reflect spatial variability and the range of the soil property (Carroll and Oliver, 2005; Corwin and Scudiero, 2016; Corwin and Scudiero, 2019; King et al., 2005). The ECa measurements are reliable, quick, and easy to take with GPS-based portable equipment; therefore are well-suited for characterizing soil salinity spatial variations. There are successful applications of EMI using DualEM instrument in soil salinity mapping (Corwin and Lesch, 2005b; Guo et al., 2015; Hy et al., 2013, 2015; Serrano et al., 2010; Yao and Yang, 2010; Yao et. al., 2016). Soil apparent electrical conductivity has been applied also in precision agriculture to delineation of management zones in order to improve nutrient management (Corwin et al., 2006; Heiniger et al., 2003; Peralta and Costa, 2013). Doolittle and Brevik (2014) used the EMI instruments for delineating soil boundaries. Greve H.G. and Greve M.B. (2004) have also applied EMI mapping to better define soil map unit delineation widths.

In Romania, few researches have been carried to assess saline soils using the EMI techniques and instruments. Voicea et al. (2009) used a VERIS 3150 to assess EC in different soil textures, while Chiş (2014) used a VERIS system to assess the spatial variability of soil properties. Teşileanu and Fedorca (2015) emphasized the need for right assessment of soil salinization and alkalinity using new methods and techniques in Romania, based on a modern analysis of soil quality. Chitea et al. (2016) measured in-situ electrical conductivity (ECa) of oil and salty water contaminated soils using portable electromagnetic induction instruments.

The main goal of this research was to: 1) identify the soil type in accordance with Romanian System of Soil Taxonomy, 2012 and 2) assess spatial variability of salts using an electromagnetic instrument to demonstrate its low cost and high accuracy in measuring and mapping soil salinity in the Valea Sărată, County of Cluj.institutional practices.

2. Material and methods

2.1. Site description

The pilot area was part of the Sărăturile (Salts) and Ocna Veche Nature Reserve, a protected area of national interest that corresponds to the 4^{th} IUCN category (mixed nature reserve) situated in Cluj County within the boundaries of Turda.The natural area is located in the south-eastern part of Cluj County and the northeast of Turda, near the county road (DJ161B) connecting the town of Crairat with the national road DN15 – Târgu Mureş – Cluj Napoca. It was declared as a natural protected reservation by Law no. 5 of 6 March 2000 (concerning the approval of the National Spatial Planning Plan – Section III - Protected Areas) and covers an area of 10 hectares. The average annual temperature in Turda is 8.9° C, while the average annual rainfall recorded is 518.7 mm.The protected area (overlaid with the Nature 2000 site - Ocna Veche Plates) consists a wet area (saline lakes, salt marshes) and a less wet (pastures and meadows) resulting from salt exploitation (both on the surface and in the underground). It conserves two habitats: the *Salicornia* community and other annual species that colonize the wet and sandy lands, as well as the Pannonian and Ponto-Sarmatian meadows and marshes. In the reserve area plant associations were developed with halophilous plants of the genus Salicornia (*Amaranthaceae* family), *Liparis loeselii*, *Meesia longiseta* and *Serratula lycopifolia* - species listed on the IUCN red list of Threatened Species.In the Sărata-Turda Valley (Fig. 2), the salts were formed under the influence of saline marls containing more than 0.3% mineral residue. There are also frequent salty coastal springs which have further led to the salinization of the soils in the valleys and meadows (Miclăuş, 1991).

2.2. Soil sampling

The survey was conducted in September 2016. The period was chosen based on different studies (Florea and Dumitru, 2002; Niţu and Drăcea, 1981) which concluded that autumn (September to October) is the best time to collect soil samples for Solonchak evaluation, due to seasonal variation in total salt content.

After scanning the study area, three soil profiles were obtained. The soil samples were collected at different depths (0 to 20, 20-40, 40-60 cm depth). Profiles locations were chosen across the valley from coast to coast (Fig. 2).

Fig. 2. Map of the study area in Valea Sărată (www.google.com/maps). Locations of the soil profiles (P1, P2 and P3), water channel and the wet area

Soil samples were collected in plastic bags and weighed immediately before drying, then oven-dried at 105°C, sieved with 2 mm mesh, homogenized and stored in sealed recipients before analysis in the lab according to the Methodology of Pedological studies (Florea et al., 1987). Analyses were carried out for particle size distribution using the pipette method, electrical conductivity (ECe, mS) was assessed by soil saturated paste extraction method and a conductivity meter, water-soluble cations (Na^+, K^+, Ca^{2+} and Mg^{2+}) were generated from the paste extract, while humus content was evaluated using the oxidation method, pH in soil-water solution (1:1).

Dual EM instrument

The apparent soil electrical conductivity (ECa) can be measured using the EMI technique by inducing an electrical current in the soil. (Brevik et al., 2006). ECa measurements relate directly to the magnitude of the eddy-current loops and the depth of the soil, as a result of the amplified signals of the secondary electromagnetic field induced in each loop and intercepted by the instrument's coil receptor. (Abdu et al., 2007; Abdu, 2009; Corwin and Lesch, 2005a). The sum of the intercepted signals is formed into an output voltage related to a depth-weighted soil electrical conductivity.

In this research, a DualEM-2S instrument (Fig. 3) was used.

(a)

(b)

Fig. 3. Data collection using DUALEM-2 (a) general image of the area, (b) crust and salt tolerant plants

It has a dual-geometry sensor with 2-m separation between its transmitter and dual receivers. In this way, the depths of conductivity measurements are at 1m and 3m, respectively (70% cumulative-sensitivity standard). The DualEM-2S was controlled through its RS-232 port and supplied with power through the same connector by integrating the NMEA-format measurements with GPS positions on a logger.

Totally, 3,630 points of two plots have been scanned (1st plot of 4.7 ha – South and 2nd plot of 7 ha - North) in dry conditions. As previous researches identified a trend of increasing ground conductivity with the change of temperature (Abdu, 2009), measurements were made in a stable interval of air temperature (25-27^0 C).

2.3. Data interpretation

DualEM data measurement was checked to determine the redundant values (outliers) and then interpolated using the Geostatistical Analyst Geostatistics module of the AcrGIS program. Before interpolation, the dataset was checked to determine whether the data were modelled for normal distribution or not. Skewness and excess Kurtosis were calculated using geostatistical procedures. The level of asymmetry in a dataset is best expressed by skewness values which give an input of the probability distribution for a random variable - its mean. If skewness is <-1 or >1, distribution is highly skewed; from -1 to -0.5 or between 0.5 and 1, distribution is moderately skewed; if skewness is between -0.5 and 0.5, distribution is approximately symmetric. For large sample size (>200), the absolute value for acceptable skewness is 1.5 (Goovaerts, 1997). For the analysed data set, a skewness value of 1.28 was determined indicating a normal distribution. The excess Kurtosis index indicates the shape of a central peak relative with a standard peak. Values may range from -2 to ∞. For the analysed data set, the excess Kurtosis value was -1.67. Negative excess Kurtosis means that the distribution is less peaked with less frequent extreme values than normal distribution (Webster and Oliver, 2007).

The method used for kriging interpolation was predictive so that the nugget/sill ratio of the chosen interpolation pattern was the lowest possible. The resulting interpolation was exponential with a residual error of 1.2 m. Thus, the nugget/sill ratio of <25% (in the present case, 16.3) indicates that there is a strong spatial dependence of variables, and local variations were identified with great accuracy by the maps.

3. Results and discussion

3.1. Soil taxonomy

From a taxonomical point of view, salt-affected soils are assessed using the main specific diagnostic horizons: salic horizon (sa), hyposalic horizon (sc), natric horizon (na), solonetzic horizon (Btna), hyponatric horizon (ac), and sulphuric horizon (su).

According to these criteria, the main soil types affected by salts in Romania belong to the Salsodisols Class, comprising 2 types of soils - solonchaks and solonetz.

According to the new classification system, the Romanian System of Soil Taxonomy (Florea and Munteanu, 2012), salsodisols are defined by the presence of saline (sa) or natric (na) horizon within 50 cm of the soil surface or natric-argic B horizon (Btna).

In order to denominate and characterise the soil in the area, 3 soil profiles have been analysed, using morphological, physical and chemical properties. Solonchaks have ochric or mollic horizon (Ao or Am), and an intermediate horizon (AC, AG, BG) in association with a saline horizon (sa) in the first 50 cm.

In soil profiles P1 and P2, the salic horizon (sa) was detected within the first 50 cm depth (Fig. 4a), the soil surface have been covered with salt crust most of the time (Fig. 4b). The crust is a typical feature of the solonchaks, a result of water evaporation under high evapotranspiration conditions. Consequently, a specific landscape forms due to toxicity of cations and high osmotic pressure of the water. No other diagnostic horizons have been identified. In the case of the third profile, salts were under 50 cm depth (Fig. 4), indicating a saline subtype of a different soil type.

ECe values confirmed the presence of salic horizon for profiles 1 and 2, and salinity horizons for profile 3 (Table 1). Low salt concentration in profile 3 is the result of its location on the slope, which causes salt to be washed off in lower areas. Profiles 1 and 2 were opened in the depression area where the runoff from the slopes accumulated alongside. Thus, there is a difference in the soils formed on the lower coastline and those in the depression area. This situation confirms that soil ECa mapping can be used for delineating soil boundaries in correlation to soil properties as Kühn et al. (2009) and Moral et al. (2010) stated. According to diagnostic horizons as well as to physical and chemical results, the taxonomic denomination of profile 3 corresponds to regosol eutric salinic (Eutric Salic Regosol) (IUSS WRB-SR, 2015), while the 1st and 2nd profiles are typical solonchaks (Haplic Solonchaks, WRB-SR). Solonchaks are formed when soils are affected by the presence of neutral salts such as sodium chloride (NaCl) and sodium sulphate (Na_2SO_4). The most involved cations are sodium (Na^+), calcium (Ca^{2+}), magnesium (Mg^{2+}) and potassium (K^+). By the nature of the anions depending on the value of the ratios of the ions of Cl^-, SO^4, HCO^{3-}, the solonchaks may be chloride, sulphate, bicarbonate or transition from one to the other (Table 1).

(a)

(b)

Fig. 4. (a) Soil profile P3 (salt accumulation on soil under the first 50 cm depth), (b) crust of salts in patches which determine the loss of the halomorphic vegetation (*Salicornia herbacea*)

Table 1. ECe and water-soluble cations

No/ depth	*The name of the analysis / Unit*									
	ECe, mS/m		*Ca mg/me 100g soil*	*Mg mg/me 100g soil*	*Na mg/me 100g soil*	*K mg/me 100g soil*	*HCO_3^- mg/me 100g soil*	*Cl^- mg/me 100g soil*	*SO_4^{-2} mg/me 100g soil*
	Value	*Significance*							
P1 0-20	0.24	low	7.5/0.37	0.91/0,07	17/0.73	7.5/0.19	36.6/0.6	19.52/0.55	32/0.66
P1 20-40	0.5	medium	17.5/0.87	8.81/0,72	37.8/1.63	25.75/0.66	73.2/1.2*	27.5/0.77	48/1.0
P1 40-60	1.2	high	7/0.35	3.04/0.25	122.5/5.3	2.5/0.064	65.57/1.07*	85.2/2.4	70.4/1.46
P2 crust	15	high	33.5/1.67	7.6/0.62	1800/78.2	6.75/0.17	21.35/0.35	2414/68	208/4.33
P2 0-20	6.91	high	8/0,4	1.85/0.15	800/34.78	1/0.025	50.32/0.82	1047.2/29.5	128/2.66
P2 20-40	9.21	high	10.5/0.52	1.21/0.1	1150/50	1/0.025	33.55/0.55	1491/42	99.2/2.06
P2 40-60	22.4	high	23/1.15	13.9/1.15	2600/113	2.5/0.064	27.45/0.45	3798/107	99.2/2.06
P3 0-20	0.168	low	11.5/0.57	6.99/0.57	2,5/0.1	2.25/0.057	22.87/0.37	37.27/1.05	12.8/0,26
P3 20-40	0.186	low	11/0.55	1.52/0.12	8.25/0.35	0.25/0.006	25.92/0.42	9.76/0.27	22.4/0.46
P3 40-60	0.366	low	13/0.65	2.43/0.2	26/1.13	0.0	25.92/0.42	21.3/0.6	54.4/1.13

Table 2. Chemical properties of soil profiles and the intensity of salinization (MPS, 1987)

No.	*pH (H_2O)*	*$CaCO_3$*	*Hydrolytic acidity*	*Total exchangeable basses*	*Cation exchange capacity*	*Percentage base saturation*	*Humus*	*Cl^- mg/100g soil*	*SO_4^{-2} mg/100g soil*
1	7.85	4.46	3.43	49.71	53.14	93.54	5.71	non saline	non saline
2	9.05	0.85	1.71	21.2	22.91	92.53	3.11	slightly saline	non saline
3	8.96	2.97	1.37	37.2	38.57	96.44	2.75	moderately saline	slightly saline
4	8.26	12.34	1.54	49.5	51.04	96.98	2.23	very strong saline	moderately saline
5	9.14	9.14	1.28	49.3	50.58	97.46	2.38	very strong saline	moderately saline
6	8.77	8.51	1.45	49.5	50.95	97.15	1.66	very strong saline	slightly saline
7	8.28	8.72	0.94	49.4	50.34	98.13	1.76	very strong saline	slightly saline
8	7.56	3.61	1.88	39.6	41.48	95.46	5.29	slightly saline	non saline
9	7.90	5.74	0.85	49.5	50.35	98.31	3.73	non saline	non saline
10	8.14	8.29	1.20	49.3	50.5	97.62	1.45	slightly saline	non saline

Table 3. Soil water constants and texture of soil profiles

No.	*Hygroscopic coefficient*	*Wilting coefficient*	*Texture*
1	6.55	9.82	clay loam
2	8.34	12.51	medium clay
3	7.85	11.77	medium clay
4	3.66	5.49	loam sandy clay
5	6.60	9.90	silty clay loam
6	7.17	10.75	clay loam
7	10.39	15.58	medium clay
8	6.79	10.18	clay loam
9	6.70	10.05	clay loam
10	6.47	9.70	clay loam

The intensity of salinity is shown in Table 1 and the physio-chemical and soil moisture properties in Table 2 and 3. In terms of alkalization intensity, it can be noticed that only samples 2 and 3 (Table 1) are slightly alkaline, with HCO_3 values >60 mg/100 g of soil and >1 me/100 g of soil, respectively.

3.2. Spatial variation of salinity

As high spatial variation of salt-affected soils was experienced in the pilot area, the traditional methods, though reasonably accurate, had limited utility for the assessments of soil salinity (or sodicity) at field and regional scales. In field-scale studies, the EMI-based ECa measurements were rather used to assess the soil spatial variation and identify field-scale heterogeneities (Corwin and Lesch, 2008). The conductivity over the pilot area ranged from 1 to 15 dS/m which is typical in a saline area.

A major advantage of EMI is its capacity to produce a large number of georeferenced, quantitative measurements that can be associated with the spatial variability of salinity and sodicity at large scales. Fig. 5 represents the spatial variation of ECa in the pilot area at the surface.

Accumulation of salt powder or crusts on the soil surface is a sign of excessive salinization (Blanco and Lal, 2010). These accumulations corresponded to the red area in the maps (Fig. 5), where the ECa is >500 mS/m, levels that not only reduce growth of sensitive plants but also affect tolerant plants creating the "baldness".

It is clear that the depressed area was more salinized because the area was poorly drained; the soil has low permeability due to clay texture and was influenced by salt migration by capillarity from shallow water table, also collecting water and soluble compounds from the surrounding uplands. Lower values were recorded as moved away from wetter areas to higher and better drained areas where ECa values are <200 mS/m. These values corresponded to areas where eutric salic regosol was identified on the upper lands.

Fig. 6 represents the spatial variation of ECa in the pilot area at depth.

The bulk electric conductivity shows lower values (<-350 ms/m) near the water channel (Fig. 6), at 100 cm depth water in the soil profile, dissolving the soluble salts. As further moved away from the channel and from the depression area to upper lands, the salts were accumulated in soil and the apparent EC was higher, but rarely exceeded 350 mS/m.

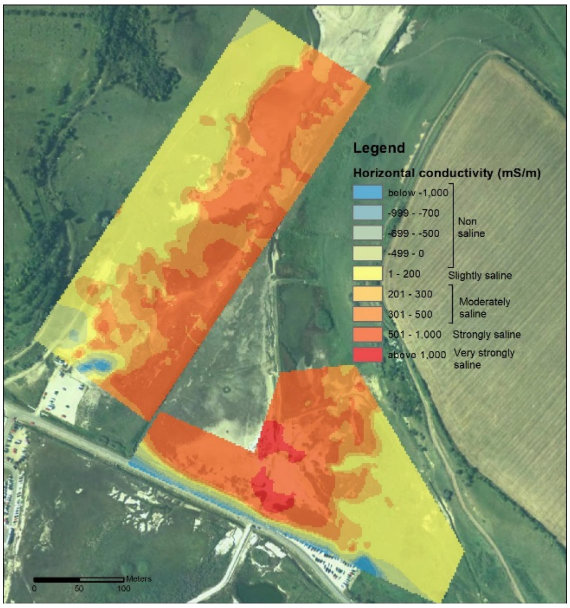

Fig. 5. Spatial variability kriged map of the apparent soil ECa in horizontal co-planar (EMHCP) (mS/m) at 0-30 cm depth

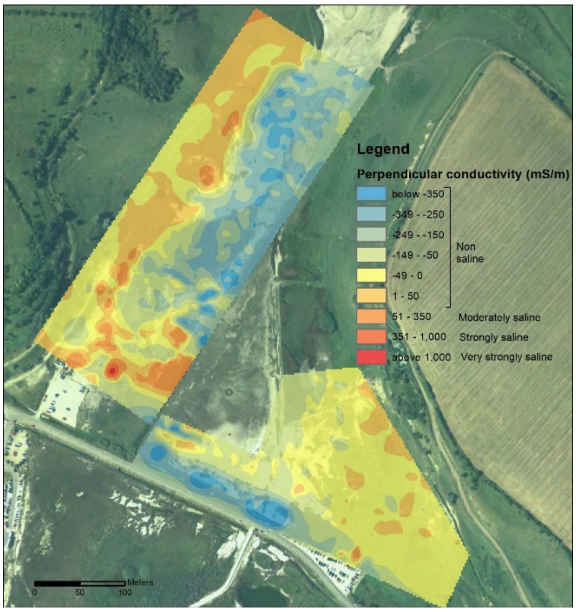

Fig. 6. Spatial variability kriged map of the apparent soil ECa in perpendicular (EMPRP) geometries (mS/m) at 100 cm depth

The spatial ECa patterns shown in Fig. 5 and 6 suggest two major soil-landscape units within the area, the valley floor and the higher-lying slope components. Lower and less variable ECa values were consistently recorded on the well-drained side slopes, while higher and more variable ECa values were observed along the valley floor, where soils were poorly-drained. Therefore, the persistently higher ECa were attributed both higher clay content and wetter soil conditions. Same results were found by Doolittle and Brevik, (2014), confirming once more that the EMI can be used for delineating soil boundaries. Greve H.G. and Greve M.B. (2004), have also applied EMI mapping to better define soil map unit delineation widths.

It has been demonstrated that fields mapped several times during the year with varying moisture contents had soil ECa value changes, but the zone delineation did not present any change. Grisso et al. (2009) found that soil ECa varies by only 5% - 10% within the exception of pure sand. As a result, variations in soil type can be detected irrespective of the moisture condition of the field.

Mapping spatial-temporal variation of soil salinity represents one of the most important steps in salinity management. However, it is not a simple process (Nouri et al., 2018), but since there is no standard method of interpretation/correlation of soil salinity values with ECa values, studies conducted up to now have used either regression equations (Sonmez et al., 2008) or modelling equations obtained by reporting to soil texture (Whitney, 2012), or multiple linear regression equations (Akramkhanov and Vlek, 2012). Unfortunately, models are imperfect and tend to be both time dependent and site specific (Lesch et al., 1998). As a consequence, calibration equations and modelled results usually cannot be extrapolated to other sites (Cassel et al., 2009).

5. Conclusions

From taxonomy point of view, based on morphological features and physio-chemicals analyses soils from the pilot area have been identified as solonchaks on the valley area, the ECe showing a very strong and strong salinity at 0-50 cm depth, while on side slopes regosols are present. In this case the salinity is lower and appear only under 50 cm depth.

A DualEM instrument for soil salinity mapping has been used and tested with good satisfactory results. The Eca map at surface correspond in terms of values with soil salinity. In the valley floor, where solonchacks prevail, the ECa registered the values above 1000 mS/m while on slopes due to well-drained conditions but still affected by salts deposits the values are under 200 mS/m. The EMI measurements at 100 cm depth showed a different distribution of salts, the lower values were registered in solochaks area due to the presence of water which dissolved the salts. In general, lower and less variable ECa values were consistently recorded on the well-drained side slopes, while higher and more variable ECa values were observed along the valley floor, where soils were poorly-drained.

The ECa mapping is important because it identifies areas in the field that have different soil composition which may benefit from different management strategies. In this case, this was helpful in establishing salinity diagnosis and soil boundaries. Field scanning was achieved in less than hours by a single operator demonstrating a high efficiency. It allows large or irregularly shaped areas to be mapped with less effort and time together with less cost of lab work, saving costs. Thus, a high amount of georeferenced data can be collected in a rapid and inexpensive manner.

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