THREE PROXIMAL SENSORS TO ESTIMATE TEXTURE, SKELETON AND SOIL WATER STORAGE IN VINEYARDS

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ABSTRACT

Proximal sensors are becoming widely used in precision viticulture, due to the quick, easy and non-invasive identification of soil spatial variability. The apparent soil electrical conductivity (ECa) is the main parameter measured by sensors, which is correlated to many factors, like soil water content, salinity, clay content and mineralogy, rock fragments, bulk density, and porosity. This study compares three different sensors to delineate soil boundaries and estimate clay, skeleton content and available water (AWC) in a vineyard of the Chianti region (Central Italy). All three sensors produced ECa maps with similar pattern. Although the correlations between ECa, clay and skeleton content were usually moderate, the correlations between ECa and some important hydrological parameters, namely field capacity (FC), wilting point (WP) and available water capacity (AWC), was very high.

KEYWORD
Soil – precision viticulture – geophysics – EMI sensors – apparent electrical conductivity.

INTRODUCTION

The use of instruments like GPS, GIS, remote sensing and soil monitoring technologies in precision viticulture is becoming common for the most important farms (Proffitt *et al.*, 2006). In particular, the knowledge of the spatial variability of soil hydrological parameters is crucial for a proper crop management, aimed at maximizing income and reducing environmental impacts of agriculture activities. In precision viticulture, it is very important to know the hydropedological variability (Morari *et al.*, 2009; Costantini *et al.*, 2009) of the vineyard to plan drainage, irrigation, tillage, fertilization etc., as well as to improve the quality of grapes and wine.

A rapid, non-invasive and relatively cheap mapping of the soil apparent electric conductivity (ECa) can be a very useful tool for identifying important soil map units and properties, in particular, clay (Morari *et al.*, 2009), water content (Davies R., 2004; Tromp-van Meerveld and McDonnell, 2009; Costantini et al., 2009), bulk density and salinity (Doolittle *et al.*, 2001). The relationships between apparent electric conductivity (ECa) and soil hydrological parameters are still under investigation (Cousin *et al.*, 2009; Doussan and Ruy, 2009).

The goal of this work was to test the suitability of three different proximal sensors in a vineyard on skeletal soils, and to relate the measured ECa with the clay content, skeleton and hydrological parameters, namely field capacity (FC), wilting point (WP) and available water (AWC).

MATERIALS AND METHODS

The studied vineyard, located in the Chianti area (Central Italy), was only 4 ha in size, but heterogeneous in soils. All soils were difficult to be surveyed with the traditional hand auger, since they were rather clayey (clay content of the fine earth ranging from 28 to 56%) and stony (from 10 to 50 %). All soils were not saline.

The sensors used for this work (Fig.1) were: a) a single-frequency Electro-Magnetic Induction sensor (Geonics EM38-DD), b) a multi-frequency EMI sensor (GSSI Profiler EMP- 400) and c) a geoelectric system (ARP-Automatic Resistivity Profiling). The EM38-DD is an EMI sensor composed by two EM38 sensors, coupled in perpendicular position (Fig.1a). Each sensor has an intercoil spacing of 1 m and operates at a frequency of 14,600 Hz. The depths of the magnetic field penetration are about 0.75 m and 1.5 m, respectively for the horizontal (HDP) and vertical (VDP) dipoles modes (Geonics Limited, 1998). The instruments sensitivity varies as a non-linear function of depth (McNeil, 1990).

The GSSI Profiler EMP-400 (Fig.1b) is a multifrequency EMI sensor, which can operate to measure simultaneously up to 3 frequencies between 1,000 Hz and 16,000 Hz, with intercoil spacing of 1.2 m. For this study we operated at 8, 10 and 15 kHz. The instrument can be used in vertical dipole mode (VDP) or in horizontal dipole mode (HDP), but the instruments sensitivity in function of depth is not still studied. The output of both the EM38-DD and Profiler is the apparent electric conductivity (ECa), measured in mS m^{-1}. Both the EMI sensors were supplied with a DGPS.

The ARP© device (Fig. 1c) was conceived by Geocarta, spin-off society of C.N.R.S. (National Scientific Research Center, France). The system, similar to a disc plough, consists of a couple of teeth discs operating as injection electrodes and of three couples of teeth discs, functioning as receivers and measuring the difference of electrical potential. The distance between each couple of receivers was conceived and calibrated to investigate three soil depths, about 0-50, 0-100 and 0-170 cm. The system, supplied with a DGPS, was pulled by a quad-bike.

Figure 1: The three proximal sensors used for this work. a) Geonics EM38-DD, b) GSSI Profiler EMP-400, c) Geocarta ARP©.

Resistivity values (ER), in Ω.m, were obtained from the intensity of the injected current and from the differences in electrical potential. These values can be easily transformed in ECa (mS m^{-1}) by the formula:

$$ECa = \frac{1}{ER} \cdot 1{,}000$$

The survey with the EM38-DD and the Profiler EMP-400 was performed on the same day in August, when soils were dry on surface, whereas the survey with the ARP was carried out in May, when soils were moister and the contact soils-electrodes better. For this work, we did not consider the temperature and the moisture content of the soils, but the textural features only.
13 points were chosen for soil sampling and texture analysis on the basis of the ECa values. The samples were “tout venant” of some kilograms because of the measurement of skeleton content.
Laboratory determination of the water content at FC and WP (v/v) was carried out by pressure plate apparatus at -33 and -1,500 kPa matric potential, respectively (Kassel and Nielsen, 1986). Each soil horizons was analyzed in triplicate, and the corresponding bulk density values were used to convert -33 and -1,500 kPa gravimetric water content to a volumetric basis. AWC was determined as the difference between water content at FC and WP.

RESULTS AND DISCUSSION

The three instruments produced similar spatial patterns (Fig.2). During the proximal survey, the EMI sensors (EM38-DD and Profiler EMP-400) in the HDP orientation registered negative or very low values in some vineyard areas. This was probably due to the interference of the iron wires of the vineyard rows or other iron materials with the magnetic field. Therefore, these wrong data (negative, or very close to 0) measured in HDP orientation were deleted before data interpolation.
As a whole, the ECa values measured by ARP device were higher, whereas the values measured by Profiler and EM-38 were similar (Tab.1).

Table 1: Descriptive statistics of ECa (mS m^{-1}) measured with the three devices. The negative and very low values were not considered.

	Profiler VDP			Profiler HDP			EM38		ARP		
	15kHz	10kHz	8kHz	15kHz	10kHz	8kHz	VDP	HDP	50	100	170
Mean	31.8	32.2	34.6	19.2	20.0	21.9	19.5	28.2	35.4	40.1	37.4
Median	26.7	26.3	29.0	15.8	16.4	18.2	19.1	23.6	32.3	33.3	29.4
Mode	20.4	17.6	23.8	14.2	14.0	16.2	19.1	15.3	28.6	34.5	100.0
Minimum	9.9	10.1	12.2	2.0	6.9	8.5	0.9	8.8	16.4	7.1	1.9
Maximum	78.8	79.4	81.6	46.2	46.7	49.0	47.9	71.6	83.3	142.9	111.1
Standard dev.	14.3	15.0	15.3	9.3	8.9	9.2	7.3	12.8	13.8	24.5	25.4

The most significant correlations between the different instruments were: ARP-50 and EM38_HDP, ARP-170 and EM38_VDP, ARP-170 and Profiler, EM38_VDP and Profiler in all the configurations (Tab. 2).

Moderate or not significant correlations resulted between clay content at 0-50 cm and ECa of all the configurations for the EM38 and the Profiler, while a better correlations resulted with the ARP-50 (Tab.3). Clay content at 50-100 cm correlated either moderately with the ECa of Profiler and EM38, or well with the ECa obtained from ARP-100. On the other hand, highly significant correlations resulted between ECa and moisture content (in mm) at FC, WP and AWC.

Table 2: Pearson correlation coefficients (r) of the three sensors (n = 99, $p < 0.01$). The most significant correlations between the different sensors are in bold. Correlation coefficient between the same device in different configurations are in italic.

	Prof_VDP15	**Prof_VDP10**	**Prof_VDP8**	**Prof_HDP15**	**Prof_HDP10**	**Prof_HDP8**	**EM38_HDP**	**EM38_VDP**	**ARP-50**	**ARP-100**	**ARP-170**
Prof_VDP15	**-**										
Prof_VDP10	*0.999*	-									
Prof_VDP8	*0.998*	*0.999*	-								
Prof_HDP15	*0.978*	*0.979*	*0.979*	-							
Prof_HDP10	*0.977*	*0.979*	*0.979*	*0.997*	-						
Prof_HDP8	*0.977*	*0.981*	*0.982*	*0.996*	*0.997*	-					
EM38_HDP	0.647	0.638	0.633	**0.710**	**0.716**	0.693	-				
EM38_VDP	**0.924**	**0.924**	**0.924**	**0.919**	**0.923**	**0.922**	*0.764*	-			
ARP-50	0.580	0.564	0.555	0.617	0.607	0.587	**0.774**	0.654	-		
ARP-100	0.699	0.688	0.683	0.717	0.710	0.699	**0.774**	**0.753**	*0.920*	-	
ARP-170	0.764	0.762	0.758	**0.783**	**0.783**	0.775	0.766	0.805	*0.801*	*0.872*	-

Table 3: Pearson correlation coefficients (r) between clay, skeleton, FC, WP, AWC and the different sensors (n = 13). Bold: $p < 0.05$; bold underlined: $p < 0.01$; normal: not significant.

	Profiler VDP			Profiler HDP			EM38		ARP		
	15kHz	10kHz	8kHz	15kHz	10kHz	8kHz	VDP	HDP	50	100	170
clay 0-50 cm	0.532	0.517	0.503	0.493	0.507	0.482	0.418	0.363	**0.682**	**0.647**	**0.608**
clay 50-100 cm	**0.610**	**0.585**	**0.569**	**0.568**	**0.578**	**0.553**	0.530	**0.587**	**0.808**	**0.815**	**0.653**
skeleton content	**-0.663**	**-0.659**	**-0.654**	**-0.723**	**-0.713**	**-0.697**	**-0.661**	-0.390	**-0.702**	**-0.631**	**-0.659**
FC 0-100 cm	**0.904**	**0.890**	**0.879**	**0.920**	**0.921**	**0.910**	**0.899**	**0.773**	**0.908**	**0.962**	**0.925**
WP 0-100 cm	**0.902**	**0.884**	**0.870**	**0.870**	**0.866**	**0.850**	**0.885**	**0.748**	**0.937**	**0.970**	**0.850**
AWC 0-100 cm	**0.923**	**0.918**	**0.913**	**0.925**	**0.942**	**0.934**	**0.937**	**0.874**	**0.834**	**0.978**	**0.749**

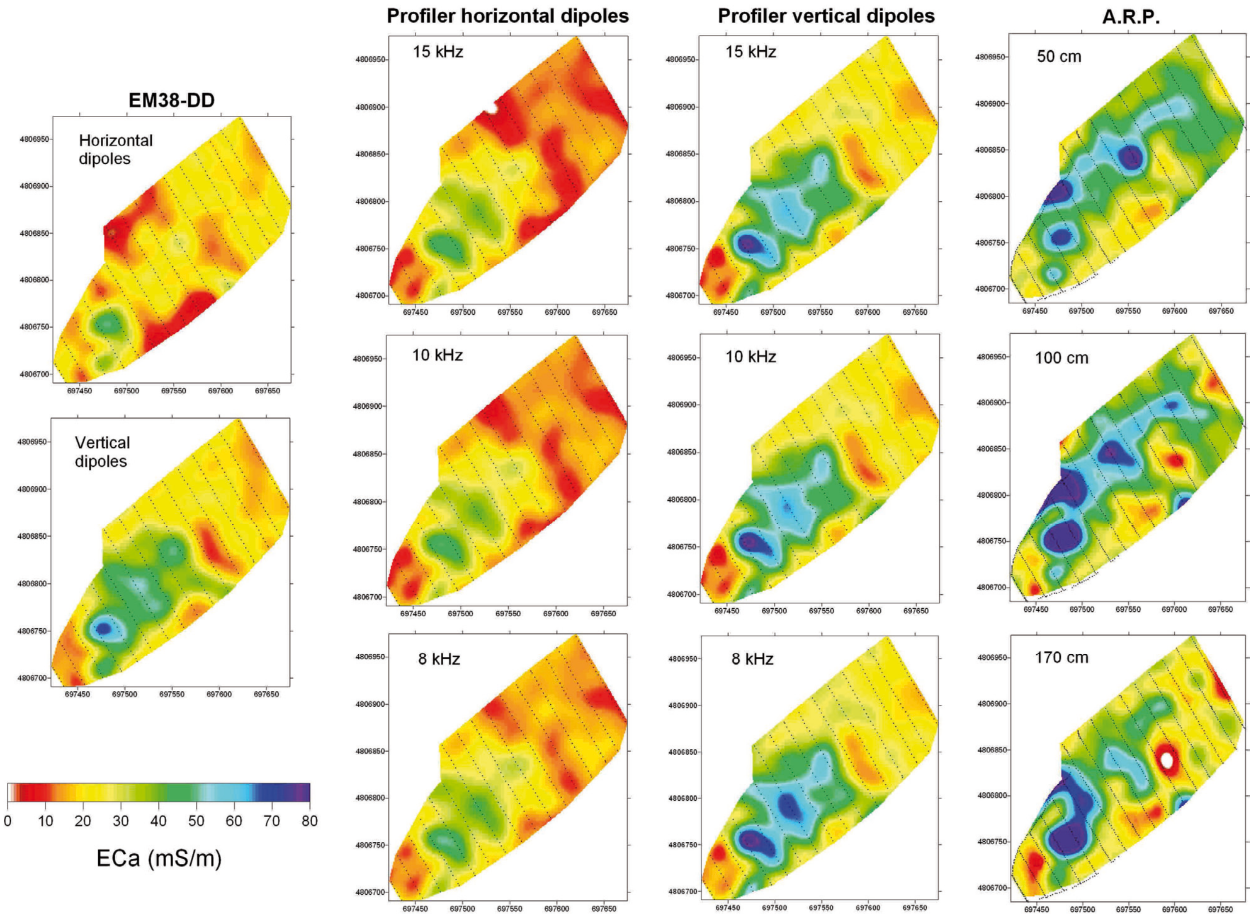

Fig.2: ECa maps of the vineyard, obtained with the three different sensors. The variogram parameters for the interpolation were the same for all the maps (ordinary kriging).

CONCLUSIONS

The ECa pattern obtained with the three sensors was similar (Fig.2). The instruments could provide for a rapid, non invasive and relatively cheap soil survey in a difficult environment, like that of a vineyard on clayey and stony soils, although iron materials in the vineyard sometimes interfered with the magnetic fields of the EMI sensors in the HDP configuration. The cumulative response of Profiler did not change at different frequencies and was very similar to the EM38_VDP response. On top of that, both sensors were strongly correlated with ARP-170, except for EM38_HDP, which was better correlated with ARP-50 and ARP-100. Correlations between ECa and hydrological parameters namely FC, WP and AWC resulted highly significant.

In conclusion, the proximal survey performed by any of these instruments can complement the traditional soil survey methods and allow a high quality predictive mapping of important soil hydrological properties like FC, WP and AWC.

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