Three proximal sensors for mapping skeletal soils in vineyards

S.Priori[A], E. Martini [B] and E. A. C.Costantini[A]

[A]C.R.A.-A.B.P., Research Center of Agrobiology and Pedology, Firenze, Italy, Email priorisimone@gmail.com
[B]University of Turin, Earth Science Department, Turin, Italy.

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, bulk density, and porosity. In the last three decades, many proximal sensors for the measurement of the ECa have been produced and commercialized. This study compares three different sensors to delineate soil boundaries and estimate clay and skeleton content in a vineyard of the Chianti region (Central Italy). The sensors were a geoelectric system (ARP-Automatic Resistivity Profiling) with 3 different depths of investigation (50 cm, 100 cm and 170 cm), a single-frequency Electro-Magnetic Induction sensor (EMI, Geonics EM38-DD), in horizontal (EM38_HDP) and vertical dipole configuration (EM38_VDP) and a multi-frequency EMI sensor (GSSI Profiler EMP- 400), in horizontal (Profiler_HDP) and vertical (Profiler_VDP) dipole configuration. All three sensors produced ECa maps with similar pattern. The strongest correlations between the instruments were between ARP-50 and EM38_HDP (r = 0.774), ARP-170 and EM38_VDP (r = 0.805), and ARP-170 and Profiler in all the configurations (r = from 0.758 to 0.783). The correlations between ECa and clay content calculated on the fine earth were low or not significant with EM38 and Profiler (r = 0.36 to 0.61), both in vertical and horizontal configuration, and stronger with ARP (r = 0.61 to 0.81). The correlation improved and resulted significant for all the sensors (r = 0.56 to 0.86) when the percentage value of clay was referred to the whole soil (fine earth + skeleton).

Key Words
EM38, ARP, Profiler, EMI sensors, apparent electrical conductivity, precision viticulture.

Introduction
In the last years, some important farms have adopted precision viticulture (Proffitt *et al.* 2006) and utilize GPS, GIS, remote sensing, soil monitoring technologies etc. To manage the spatial variability inside the vineyard, the farmer needs geo-referenced maps, displaying areas with similar soil behavior, like hydraulic permeability, water retention, soil fertility, etc. 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 soil properties, in particular, clay (Morari *et al.* 2009), water content (Davies 2004; Tromp-van Meerveld and McDonnell 2009), bulk density, and salinity (Doolittle *et al.* 2001). The goal of this work was to test the suitability of three different proximal sensors in a difficult environment, as it is a vineyard on skeletal soils, and to relate the measured ECa with the clay content.

Methods
The sensors used for this work were: i) a single-frequency Electro-Magnetic Induction sensor (EMI, Geonics EM38-DD), ii) a multi-frequency EMI sensor (GSSI Profiler EMP- 400) and iii) a geoelectric system (ARP-Automatic Resistivity Profiling). The EM38-DD is an EMI sensor composed by two EM38 sensors, coupled in perpendicular position (Figure 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 (Figure 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.

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

The ARP © device (Figure 1c) was conceived by Geocarta (France). It is an automatic system for georesistivity survey at three different depths of investigation, in our case 0.5, 1 and 1.7 m. Resistivity values (ER), in ohm.m, are 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) by the formula: ECa = (1/ER) 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. Therefore, the values of ECa measured by ARP were generally a little more elevated, because of the higher soil water content. For this work, we did not consider the temperature and the moisture content of the soils, but the textural features only.

The studied vineyard was located in the Chianti area (Central Italy) and was about 4 ha in size. The soil units of the vineyard were TOR, a Typic Haplustepts clayey-skeletal, developed on Tertiary carbonatic flysch; NEB, a Typic Paleustalfs loamy, developed on Pleistocene fluvial deposits; and MIN, an Typic Endoaquepts clayey, developed on Pliocene marine deposits. All soils were rather clayey (clay content of the fine earth ranging from 28 to 56%) and stony (from 10 to 50 %), not saline (Figure 2). Soil samples "*tout venant*" of some kilograms were taken for the measurement of skeleton content. The skeleton was classed into three classes and weighed: fine gravel (0.2-2 cm), coarse gravel (2-7.5 cm), cobbles (> 7.5 cm). The results were used to correct the calculation of the clay content (clay_corr) referred to the whole soil, fine earth + skeleton.

Figure 2. Map of soil units in the vineyard.

Results

The three instruments produced similar spatial patterns (Figure 3), which corresponded to the changes of clay and skeleton characterizing the soil map units. During the proximal survey, the EM38-DD and the Profiler EMP-400 had some problems in the horizontal dipole orientation, probably due to the interference of the iron wires of the vineyard rows with the magnetic field. Therefore, some wrong data (negative, or very close to 0) measured in HDP orientation should be deleted before data interpolation. All the three sensors produced ECa maps with similar pattern. The strongest correlations between the instruments were: ARP-50 and EM38_HDP, ARP-170 and EM38_VDP, ARP-170 and Profiler, EM38_VDP and Profiler in all the configurations (Table 1). Scarce 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 correlation resulted with the ARP-50 (Table 2). 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.

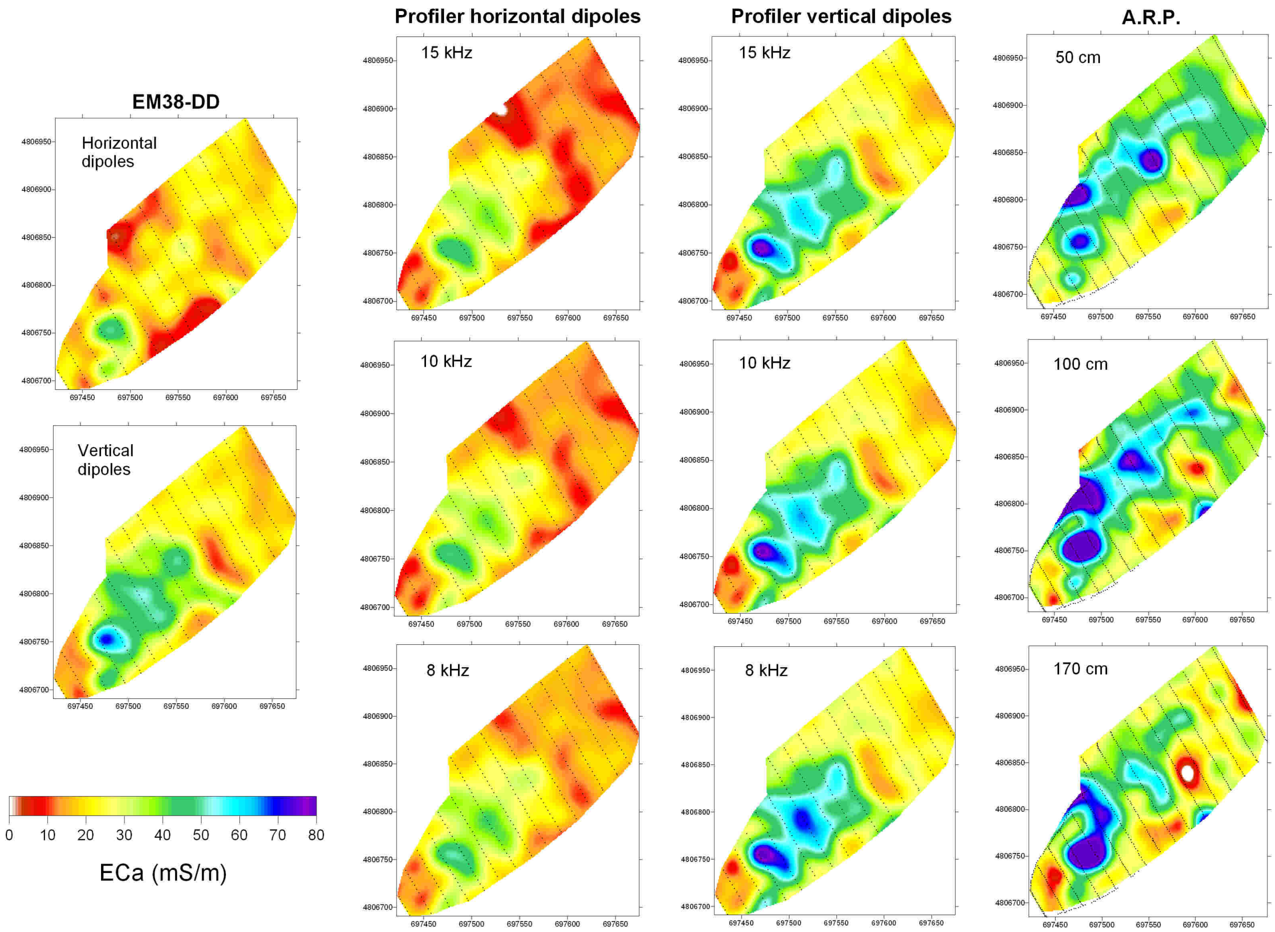

Figure 3. ECa maps of the vineyard, obtained with the three different sensors. The variogram parameters for the interpolation were the same for all the maps (ordinary kriging).

Table 1. Pearson correlation coefficients (r) of the three sensors (n = 99, probability < 0.001).

	Prof_VDP15	**Prof_VDP10**	**Prof_VDP8**	**Prof_HDP15**	**Prof_HDP10**	**Prof_HDP8**	**EM38_HDP**	**EM38_VDP**	**ARP-50**	**ARP-100**	**ARP-170**
Prof_VDP15	1.000										
Prof_VDP10	0.999	1.000									
Prof_VDP8	0.998	0.999	1.000								
Prof_HDP15	0.978	0.979	0.979	1.000							
Prof_HDP10	0.977	0.979	0.979	0.997	1.000						
Prof_HDP8	0.977	0.981	0.982	0.996	0.997	1.000					
EM38_HDP	0.647	0.638	0.633	0.710	0.716	0.693	1.000				
EM38_VDP	0.924	0.924	0.924	0.919	0.923	0.922	0.764	1.000			
ARP-50	0.580	0.564	0.555	0.617	0.607	0.587	0.774	0.654	1.000		
ARP-100	0.699	0.688	0.683	0.717	0.710	0.699	0.774	0.753	0.920	1.000	
ARP-170	0.764	0.762	0.758	0.783	0.783	0.775	0.766	0.805	0.801	0.872	1.000

The correlation coefficients improved when clay was calculated as percentage of the whole soil, fine earth plus skeleton (clay_corr). In particular, ECa measured by ARP-50 showed a strong correlation with clay_corr 0-50 cm and ARP-100 with clay_corr 50-100 cm. Medium correlation coefficients (r) were between clay_corr and Profiler in all the configurations and between clay_corr 50-100 and EM38_VDP.

Table 2. Pearson correlation coefficients (r) between clay, skeleton, clay_corr and the sensors (n = 14). Bold: probability < 0.005; underlined: probability < 0.001; 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	**0.61**	**0.585**	**0.569**	**0.568**	**0.578**	**0.553**	0.53	**0.587**	**0.808**	**0.815**	**0.653**
skeleton content	**-0.663**	**-0.659**	**-0.654**	**-0.723**	**-0.713**	**-0.697**	**-0.661**	-0.39	**-0.702**	**-0.631**	**-0.659**
clay_corr 0-50 cm	**0.655**	**0.642**	**0.628**	**0.657**	**0.658**	**0.637**	**0.567**	0.396	**0.772**	**0.735**	**0.689**
clay_corr 50-100 cm	**0.707**	**0.687**	**0.672**	**0.702**	**0.701**	**0.68**	**0.642**	**0.562**	**0.86**	**0.854**	**0.72**

Conclusion

The patterns obtained with ECa of the three sensors were similar. The instruments could provide for a rapid, non invasive and relatively cheap soil survey in a difficult environment, like that of a vineyard on stony soils, although the iron wires of the rows interfered with the magnetic fields of the EMI sensors in the horizontal dipoles configuration. The cumulative response of Profiler does not seem 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.
The correlation between ECa measured by sensors and clay content was higher with the ARP system. On the other hand, the correlation with ECa and clay_corr was strong for all sensors, except for EM38_HDP. The proximal survey made by any of these instruments can allow to map and spatialize data of clay or clay corrected for the skeleton content (clay_corr) with negligible errors.

Acknowledgements

The authors are grateful to Annamaria Castrignanò, Donatello Sollitto and Daniela De Benedetto (CRA-SCA, Bari, Italy) for the loan, the advices and the assistance with the EM38-DD, as well as to the SO.IN.G and the Geostudi Astier (Livorno) for the loan and the collaboration with the ARP and the Profiler EMP-400, respectively. A special thank is for the farm "Barone Ricasoli s.p.a.", Gaiole in Chianti, Siena (Italy) for the economic support of the research and for granting the access to its vineyards.

References

Davies R (2004) Mapping soil properties for irrigation development in the Riverland of South Australia using EM38. In 'SuperSoil 2004, 3d Australian and New Zeland Soils Conference, 5-9 December 2004, University of Sydney, Australia'. published on CD_ROM. http://www.regional.org.au/au/asssi/supersoil2004/s5/oral.

Doolittle J, Petersen M, Wheeler T (2001) Comaprison of two electromagnetic induction tools in salinity appraisals. *Journal of Soil and Water Conservation* **56**, 257-262.

Geonics Limited (1998) EM38 ground conductivity meter operating manual. Mississangua, Ontario, Canada. www.geonics.com

McNeil JD (1990) 'Geonics EM38 Ground Conductivity Meter: EM38 Operating Manual'. (Geonics Limited: Ontario, Canada).

Morari F, Castrignanò A, Pagliarin C.(2009) Application of multivariate geostatistics in delineating management zones within a gravelly vineyard using geo-electrical sensors. *Computers and Electroncis in Agricolture* **68**, 97-107.

Proffit T, Bramley R, Lamb D, Winter E (2006) 'Precision Viticulture'. http://www.pvaustralia.com.au/book.html

Tromp-van Meerveld HJ, McDonnell JJ (2009) Assessment of multi-frequency electromagnetic induction for determining soil moisture patterns at hillslope scale. *Journal of Hydrology* **368**, 56-67.