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MEASUREMENT OF SOIL ELECTRICAL PROPERTIES FOR THE CHARACTERIZATION OF THE CONDITIONS OF FOOD CHAIN ELEMENT TRANSPORT IN SOILS. PART I. INSTRUMENTAL COMPARISON

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Introduction

The need for more detailed soil information on soil conditions, determining food chain element transport in soils has lead to increasing interest over indirect methods for mapping soil properties. These methods allow overcoming the costs of detailed soil mapping based on traditional sampling. The measurement of bulk soil electrical conductivity (EC_a) has been seen as one of the most promising methods, in which input levels in agricultural production can be targeted more accurately both to improve the yield and decrease the environmental damages; because of the ease of measurement and good correlations with soil properties which affect yield potential and environmental factors, with soil salinity and soil water content, and in non-saline soils with clay content, organic matter content and plant available nutrients. A large variety of sensors based on different techniques are available to measure soil EC_a, including electromagnetic methods with EM-induction (McNeill 1980) or TDR method (Dalton 1984), four electrode resistivity/conductivity sensors (Rhoades et al. 1999) and capacitive probes.

Typical for Hungarian plains, as in Apaj region in this case, is that the changes in soil properties are very common because of the mosaic structure of soil formation caused by repetitive river floodings and aerial transport combined. To thoroughly map the differences a large amount of soil samples would be needed. Therefore during years 2004-2005 as a joint research between MTT Finland and RISSAC, Hungary a series of near surface geophysical measurements were done with the aim of comparing different instruments in measuring soil properties

Materials and methods

In order to evaluate differences between the instruments in Apaj region, 60 km to south from Budapest three 70 meter long experimental transects were established. Within each transect, soil apparent electrical conductivity (EC_a), permittivity (ε) and volumetric water content (θ) measurements were carried out with one meter intervals and samples for soil physical and chemical properties were taken from every fifth measuring point, resulting altogether in 210 field instrumental measurement points and 45 soil sampling points with two sampling depths. The first transect was chosen to cross field areas with different cultivation practices used and crops grown, but clear textural change was avoided. In the second transect, the main interest was in mapping soil salinity, and transect was set up in salt-affected grassland. The third transect crossed the border between Robinia pseudoacacia tree plantation and field sown with winter wheat.

Devices used in the study included EM instrument (EMRC-120, Hungary), two Four electrode resistivity sensors (Martek Instruments Inc., USA and Conductivity fork, Puranen et all 1999, referred as M_ec and CF_ec) and a capacitive probe 'Percometer' (Adek ltd, Estonia, P_ec). The EM instrument consists of two coils separated by one meter, the receiver coil measures small changes in electromagnetic field generated to soil by the transmitter coil and the values can be transferred into values of EC_a of the soil (McNeill (1980). The depth response of instrument depends on coil spacing, measuring frequency and conductivity of soil, resulting in approximately 1.5 m and 1.0 m measuring depth when measured at soil surface and carried at the height of 0.70 m, respectively. The "Four electrode resistivity sensors" measure a voltage drop between inner electrodes when small current is passed through outer electrodes and show conductivity readings. In general sensing depth is approximately half of outer electrode spacing (Rhoades et al., 1999). "Martek" uses dipole configuration with 0.90 outer electrode spacing and the "Conductivity fork" "Wenner array" with evenly spaced electrodes with 0.48 m outer electrode spacing resulting in effective measuring depths approximately 0.45 m and 0.25 m, respectively. "Percometer" measures only small soil volume (point measurement) and measurements were taken at the depth of 0.20 m. Soil moisture content and permittivity was measured with two capacitive instruments (BR-30, RISSAC, Hungary, 0.10 m, VolW) and Percometer (Adek ltd, Estonia, 0.20 m, P_per).

Results and discussion

Correlation coefficients between the 8 instruments readings collected with five different instruments are presented in Table 1. The result of two DC devices (M_ec and T_ec) and that of capacitive probe (P_ec) were seemingly similar in measuring of soil EC_a ($R=0.76$-0.99, $P<0.01$). Main differences were caused by different depth responses from the instruments, as shown by highest readings obtained with M_ec (response from 0-0.45 m) and lowest by P_ec (taken at the depth of 0.20 m) supporting the findings of Sudduth, 1998. Also the two capacitive soil moisture probes correlated well ($R=0.81$, $P<0.01$) in all three transects (Table 1). During the measurements, the prototype EM instrument confronted some problems in stability and sensitivity, and in general it reacted similarly as other three EC_a instruments only in saline soils. Also sensors drift occurred in third transect presumably related to instrument warming up (Fig 1). Despite returning the instrument to the manufacturer after measurements, problems with drift remained. Therefore, besides salt affected area, usability of the prototype EM instrument was found limited because of inadequate sensitivity and reliability of operation.

Table 1. Correlation coefficients between different instrument readings in three transects (n=210). Values in Bold are statistically significant ($p<0.01$)

	EM_ground	EM_lifted	M_ec_shallow	M_ec_deep	CF_ec	P_ec	Volw
EM_lifted	0.95	1					
M_ec_shallow	0.76	0.84	1				
M_ec_deep	0.80	0.88	0.99	1			
CF_ec	0.79	0.87	0.98	0.99	1		
P_ec	0.89	0.95	0.92	0.94	0.94	1	
Volw	0.36	0.25	-0.01	0.02	0.01	0.24	1
P_per	0.33	0.20	-0.04	-0.02	-0.09	0.13	0.81

Measured EC_a values ranged from 5 mS m^{-1} in sandy soil (soil moisture content 16 m^3 $100m^{-3}$) to approximately 1000 mS m^{-1} (40 m^3 $100m^{-3}$) in saline soil (Fig 1). EC_a at saline soils exceeded reliable operation range of instruments developed for Nordic conditions, 100 mS m^{-1} for Percometer and ca. 500 mS m^{-1} for conductivity fork, with no saline soils present. Highest measured values suggest that for mapping of soil salinity measuring range should be 2000 mS m^{-1} as suggested by (Rhoades et al., 1999).

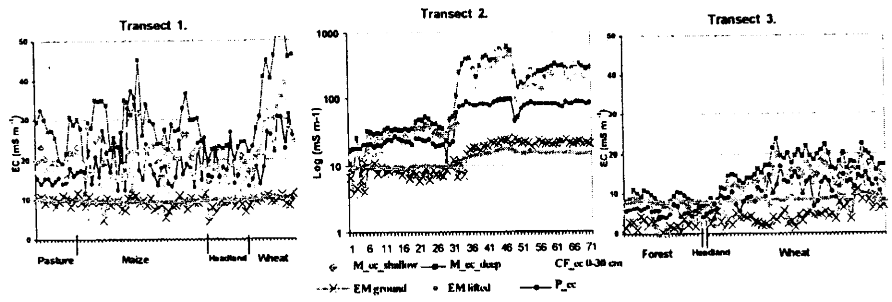

Figure 1. EC_a values measured with EMRC-120 lifted (0-1.0 m), EMRC-120 ground (0-1.5 m), Martek_shallow (M_ec 0-0.20 m), Martek_deep (M_ec 0-0.45 m), Conductivity fork (CF_ec 0-0.25 m) and Percometer (P_ec 0.20 m) in 3 transects

Both tested capacitive soil moisture probes were unsuitable for measuring soil water content in salt affected soils with high electrical conductivity. For both, reliable operation limit for EC_a was about 100 mS m^{-1}, corresponding approximately to 1 mS cm^{-1} soil paste EC. In salt affected areas measuring range for soil EC_a should exceed 1000 mS m^{-1} with adequate sensitivity for mapping of soil salinity.

Conclusions

Instruments with deepest depth response generally produced also higher EC_a values, reflecting the gradient of salts and moisture in soil from surface to deeper layers. The EM instrument was less sensible to changes and not as stable as the others. Highest measured values suggest that measuring range should exceed 1000 mS m^{-1} for mapping soil salinity. Capacitive soil moisture probes were unsuitable for measuring soil water content in salt affected soils with high electrical conductivity. It was concluded, that the measured values reflected well differences in soil properties – e.g. soil texture, salt, water and organic matter contents of soil, - influencing food chain element transport and the applied methods can be used for mapping the spatial pattern of these properties.

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