Use of the BOs-1EP for the low-sample estimation of the spatial distribution of grain sizes

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Abstract
The soil sensor system BOs-1EP, developed by the University of Applied Sciences Osnabrück, is presented here. The measuring principle is based on recording complex electrical conductance using just one pair of electrodes. The BOs-1EP is principally used to perform geoelectrical measurements in the topsoil. The measurement readings constitute a basis for the low-sample estimation of the spatial distribution of grain sizes. In addition, the readings taken using the BOs-1EP are compared to those determined using the commercial measuring systems ARP03 and EM38. The correlations between the EC values and grain sizes determined by the BOs-1EP are equally good, and sometimes even better, than the ARP03 measurement readings. While there is only weak correlation between the EC values of the EM38 and the grain sizes in the topsoil.

Key Words
BOs-1EP, digital soil mapping, soil particle size, estimation, precision farming, electrical conductivity.

Introduction
Small-scale soil information is of vital importance to economically (Kielhorn und Trautz 2007) and ecologically (Trautz *et al.* 2007) successful plant production. There is often a correlation between an unsteady level of yield and the characteristics of the soil (Scheffer & Schachtschabel 2002). If small-scale soil information, such as the type of soil, is available to agriculturists, applications (Brozio 2004; Gebbers 2004; Roth 2004) and cultivations measures (Voßhenrich 2003) can be aligned to the respective types of soil, and optimised. The small-scale soil mapping required for such information can be performed using innovative mapping methods, e.g. using soil sensors. A new soil sensor system (BOs-1EP) with the measuring principle "recording complex electrical conductance" was developed within the research projekt PIROL at the University of Applied Sciences Osnabrück. The BOs-1EP is specifically designed for taking geoelectrical measurements in the topsoil. A precise measuring depth and a defined measuring volume can be assigned to the measurement reading (HINCK 2009). Using the measurement readings, an area can be divided into subareas. For instance, a field can be divided into subareas using the cluster method (Hinck *et al.* 2006) or by dividing electrical conductance (EC) into classes (Hinck *et al.* 2008). These subareas can then be singled out for soil analysis and sampling (Hinck *et al.* 2009).

Methods
Measuring principle of the BOs-1EP
The measuring principle of the BOs-1EP is based on recording complex electrical conductance. The values measured are the magnitude, the phase shift and the noise of the electrical signal. The electrical conductance and electrical capacity of the plate assembly can be computed from the magnitude and the phase shift. Electrical noise describes the contact quality between the measurement plates and the soil. In addition, the soil temperature is taken using an infrared thermometer. Two 180 cm^2 metal plates act as electrodes. The BOs-1EP is attached to the tail hydraulics of a tractor (Figure 1) and the metal plates are dragged through the soil (galvanic coupling). The measuring depth and measuring volume are defined by the measuring set-up and the depth control of the BOs-1EP. The electrical field between the two blades in the soil is sketched in Figure 2. It can clearly be seen that the electrical field is located between the pair of electrodes, which enables us to determine the depth and measuring volume from which the measurement reading was taken. The measurements described here were carried out with an electrode space of 26 cm and a measuring depth of 25 cm. Five individual measurements are taken within half a second, whereby the five individual values are captured within a period of approximately 50 milliseconds. The mean of the five individual values is calculated. In this way two measurement readings per second are gained. The technical data of the BOs-1EP

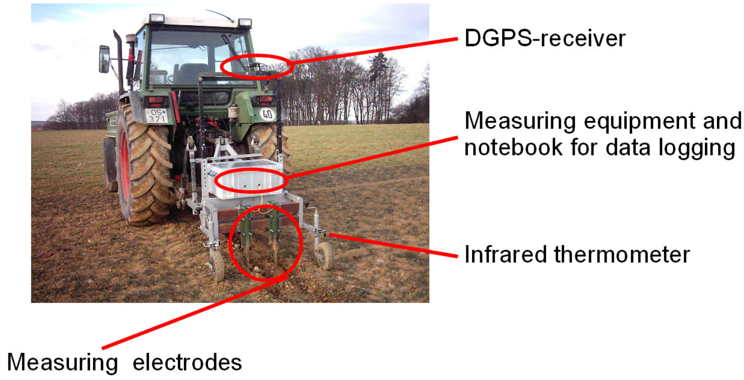

Figure 1. The BOs-1EP measurement system attached to the tractor.

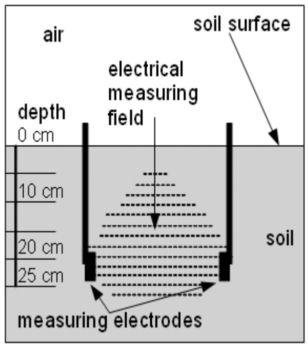

Figure 2. Behaviour of the electrical field in the soil between the pair of electrodes, BOs-1EP measurement system.

measurement system are given in Table1. We also used the commercial measurement systems EM38 and APR03 to evaluate the correlation between the grain size and electrical conductance (Table1). Thus a comparison of the results from the three measurement systems could be made.

Table1. Technical data of the three measurement systems used.

	BOs-1EP	ARP03	EM38
Measurement method	Detection of complex electrical conductance	Direct current, four-terminal electrode arrays	Electromagnetic
Electrical contact (sensor <> soil)	Galvanic (direct contact measurement)	Galvanic (direct contact measurement)	Induction (contactless)
Frequency	125,000 Hz	150 Hz	14,600 Hz
Measurement depth	Electrode depth: 25 cm	Electrode arrangement 1 (EC1) Measured depth: 0 – 50 cm	Horizontal dipole mode: 63% of the signal response describes a depth down to 60 cm
Measurement property	Defined measured volume at a defined depth	Measurement is the integral over the measured depth	Measurement is the integral over the measured depth
Date of measurement	14 March 2007	Autumn 2004	14 March 2007

"Im Berge" test field

The measuring systems were tested and evaluated on test fields of the University of Applied Sciences Osnabrück. The results are presented on the basis of the "Im Berge" test field. This field, with an area of 2.4 ha, has a very heterogeneous geological and pedogenic development (Hinck 2009). Thorough soil investigations have been carried out regarding this field. The field was subdivided into 224 10 m x 10 m grid cells (Figure 3). Mixed soil samples were taken from each grid cell, and the types of soil were identified in the laboratory. In the topsoil (at a depth from 0 to 30 cm), clay contents of 9% to 40% (Figure 4), silt contents of 21% to 40% and sand contents of 24% to 69% were determined.

Results

Correlation between grain sizes and EC

The correlations determined by the BOs-1EP are equally good as those of the ARP03. The EM38 reveals considerably weaker correlation for geoelectrical measurements in the topsoil (Table3). In the case of the EM38, the considerably larger measuring volumes and the difficulty of determining depth must be taken into account. Since there is a correlation between the EC and the grain sizes, it is possible to estimate the distribution of grain sizes using the EC readings. (Hinck 2009)

Estimation of the grain sizes using the EC

To this end, the field map containing electrical conductance was employed. It was used to select seven (virtual) sampling locations. Two grid cells with high EC readings, as well as two grid cells with low and three with moderate EC measurements were selected. The distribution of grain sizes was estimated for the 224 grid cells using the available data, the EC and the respective result of the analysis for the investigated grain size (sand, silt or clay). The accuracy of estimate is verified using the difference between the true value (laboratory value) and the estimated value (Table3). The spatial distribution of the electrical conductance and the estimated clay contents for the respective measuring system are presented in Figures 5 to 7.

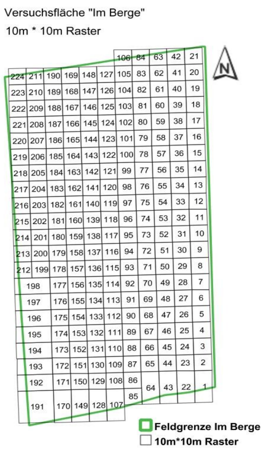

Figure 3. Sampling and evaluation grid for the "Im Berge" test field

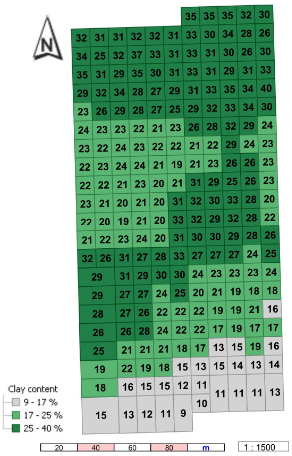

Figure 4. Spatial distribution of the clay content (in %) at a depth of 0 - 30 cm for the "Im Berge" test field

Table 2. Coefficiencies of determination between the grain size and the EC of the respective measuring system (Hinck *et al.* 2007)

Measuring System	Sand	Silt	Clay
BOs-1EP (EC25)	0.6 - 0.7	0.4 - 0.6	0.6 - 0.8
ARP03 (EC1)	0.6	0.6	0.7
EM38 (EChor)	0.2 - 0.5	0.3 - 0.6	0.2 - 0.5

Table 3. Comparison of the difference between the true and estimated sand and clay content in the topsoil of the three measuring systems used; number of grid cells with an acceptable deviation.

	BOs-1EP				ARP03				EM38			
	sand		clay		sand		clay		sand		clay	
Difference in percentage points	hits count	hits %	hits count	hits %	hits count	hits %	hits count	hits %	hits count	hits %	hits count	hits %
0	13	6	20	9	16	7	20	9	9	4	12	5
±1	42	19	69	31	39	17	67	30	32	14	57	25
±2	82	37	114	51	69	31	106	47	57	25	98	44
±3	107	48	161	72	95	42	135	60	78	35	126	56
±4	130	58	183	82	112	50	160	71	107	48	145	65
±5	153	68	201	90	130	58	177	79	132	59	161	72
±6	174	78	211	94	148	66	194	87	152	68	178	79

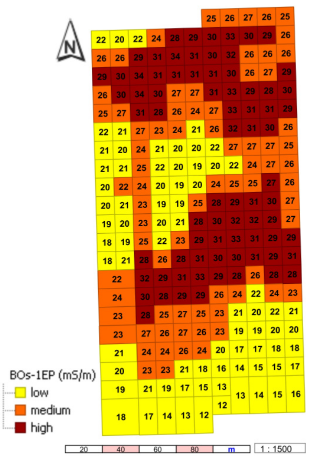

Figure 5. BOs-1EP; estimated clay content (see value in grid cell); yellow-orange-red colouring shows the spatial distribution of the electrical conductivity.

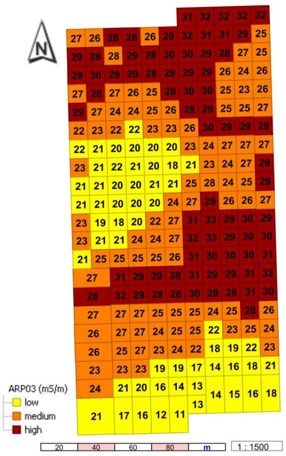

Figure 6. ARP03; estimated clay content (see value in grid cell); yellow-orange-red colouring shows the spatial distribution of the electrical conductivity.

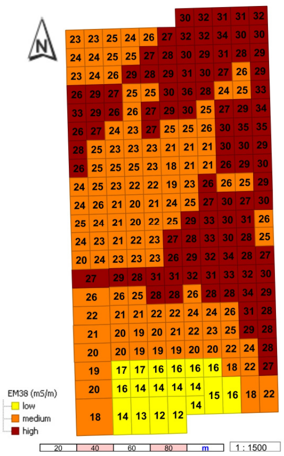

Figure 7. EM38; estimated clay content (see value in grid cell); yellow-orange-red colouring shows the spatial distribution of the electrical conductivity.

Conclusion

It is possible to take reliable geoelectrical measurements using the presented measuring principle "recording complex electrical conductance" with just one pair of electrodes. The measurement readings and the resulting correlations between the EC and the grain size demonstrate correlations that are equally good, or sometimes even better, than those of the ARP03. The estimation of the distribution of grain sizes using the EC values is accordingly accurate. The correlation between the grain size in the topsoil and the EC values of the EM38 is weaker, hence the less accurate estimation of the grain sizes. A field map with the estimated distribution of grain sizes forms the basis of precision soil sampling, which avoids inaccurate mixed soil samples, e.g. from sandy and silty parcels. Misinterpretations of the soil analysis results are therefore minimised. Such field maps can be used to support further management decisions (e.g. determining lime requirements).

Acknowledgement

This research is in the context of the project "PIROL" and was funded by VolkswagenStiftung.

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