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SITE-SPECIFIC SOIL MAPPING BY ELECTROMAGNETIC INDUCTION

E. NEUDECKER, U. SCHMIDHALTER, C. SPERL, T. SELIGE

Chair of Plant Nutrition, Department of Plant Sciences, Technical University of Munich
Am Hochanger 2, 85350 Freising
E-mail: schmidhalter@weihenstephan.de

ABSTRACT

In a German wide Precision Farming project 2800 ha of arable land in largely different geographic and climatic zones were mapped by electromagnetic induction. Data of the apparent electrical conductivity (EC_a) were compared to various other information sources (national soil inventory, yield maps and spectral information from airborne remote sensing). Multi-temporal measurements showed comparable patterns in EC_a over time. Zones of different soil substrates could be better delineated by electromagnetic induction than by the previously existing information from the national soil inventory. The latter information was related to EC_a with r^2 0.01-0.71. The closest relationship was found at the more heterogeneous sites. On heterogeneous field sites, good correlation to yield could be found with r^2 up to 0.71. EC_a measurements represent a fast technique to map soil heterogeneity.

INTRODUCTION

Site-specific management requires detailed information about the heterogeneity of fields to adapt soil cultivation, seeding, fertilising, fungicide and herbicide application to the locally varying soil conditions. In some countries, previously existing soil information from conventional soil coring may be available. However, such data seldom match the requirements either with respect to the intensity of the required soil sampling or with respect to the quality of the derived maps to delineate management units. Conventional methods however are too costly and time-consuming. Preferably fast, non-contacting methods should be available to obtain the required information. Electromagnetic induction and remote sensing imagery may allow to achieve this goal. Both techniques have been applied in a German wide project covering different geographic zones and farm types, encompassing farms varying in size from 30 ha to about 8000 ha. The soils investigated represented a large range of different soil series. This report presents the results from the electromagnetic induction mapping of the soils, describes a robust and efficient technique to conduct the electromagnetic induction survey and presents first results of the interpretation of the obtained information by also comparing to other sources of information including soil surveys conducted during the national soil inventory about 40 years ago, yield mapping and remote sensing imagery.

MATERIALS AND METHODS

This study has been carried out on eight different farms totalling an area of more than 12000 ha whereof 2800 ha were mapped by electromagnetic induction. Electromagnetic induction represents a fast non-contacting method to get information about the heterogeneity of soils. Electrical conductivity represents the influence of several factors but is mainly dependent on clay content, water content and the electrical conductivity of the soil solution. Details of the method have been described in a companion paper (Schmidhalter et al. 2001). Mapping was conducted with an EM38 (Geonics Ltd, Mississauga, Ontario, Canada) in the vertical mode in 1998 and 1999 mainly in spring or autumn.

Maps of the apparent electrical conductivity (EC_a) of 73 fields were produced. To better understand the influence of mapping conducted during different times of the year measurements were conducted twice on one field to investigate the seasonal influence. The main purpose of this study was to compare maps of EC_a to other sources of information representing spatial heterogeneity. This included sensing by remote imagery (Selige and Schmidhalter, 2001). As a potential valuable source of information data from the national soil inventory (Reichsbodenschätzung) were compared. This information has been obtained about 40-50 years ago and was digitally compiled by Dr. E. Reiche, Universität Kiel, Projektzentrum Ökosystemforschung, and Mrs Reh, Agrosat GmbH, Wulfen. A further data source which has been included were recent yield maps. Data from the farm site Wulfen were provided from Mrs Reh, Agrosat, Wulfen, and from Mr Noack, geo-konzept GmbH, Gut Wittenfeld, Adelschlag.

Correlation coefficients were calculated between EC_a and the other sources of spatial information. The bulk of the results presented in this study was from the site Wulfen. This site is situated in the Eastern part of Germany 100 km south-east from the highland ranges of the Harz. The annual precipitation averages 450 mm. The investigated soils are very heterogeneous with soil texture ranging from sand to clay loam. Some other fields included were from Kassow in the north-east of Germany. This landscape is a slightly undulating ground moraine area, dominated by glacial till. The average annual rainfall is around 550 mm.

RESULTS AND DISCUSSION

On-line measurement of the electrical conductivity

A robust and fast technique has been developed which allowed daily performances of up to 150 hectares per day. The speed of mapping was largely limited by the size of the fields. An EM-38 sensor was mounted on a sledge which was pulled by a car equipped with a DGPS. On-line information of EC_a with a resolution of 5x20 m was obtained. Fields were characterised with more than 100 measurement data points per hectare.

Maps of the apparent electrical conductivity

Maps of the apparent electrical conductivity were created for 2800 ha arable soils from 72 fields. The information obtained represents eight different farms in Germany covering largely differing geographic zones with contrasting soil types. A map of the electrical conductivity of 360 ha encompassing four fields is shown in FIGURE 1. The electrical conductivity varied from very low values, 5-10 mS m^{-1}, up to 100 mS m^{-1}. Generally speaking low values are typical for sand soils (5-15 mS m^{-1}) and higher values (30- 60 mS m^{-1}) represent more clayey soils with intermediate ranges typical for loamy soils. Very high values (over 60 mS m^{-1}) seem to reflect a preponderant influence of a high degree of water saturation, frequently in combination with loamy-clayey soils or organic soils, and additionally the influence of a relatively high soil solution salinity. Medium values can also indicate soils containing a high amount of gravel stones. This preliminary interpretative values are currently subjected to detailed soil analysis. Maps of the electrical conductivity allow to delineate zones of different soil substrates with a high degree of accuracy.

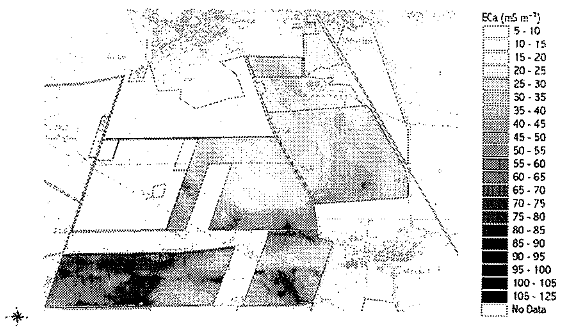

FIGURE 1. Map of the apparent electrical conductivity (EC_a) of four fields 360 ha in size.

Multi-temporal measurements of the electrical conductivity

Data of the electrical conductivity were obtained during different seasons of the year. Whereas measurements at field capacity are to be preferred for soil texture mapping, parallel investigations in summer or autumn may indicate changes in water content. The trafficability of the fields is limited by very high soil water contents. High biomass stands impose restrictions on the time when measurements can be conducted. Measurements are most conveniently conducted on bare soil, but measurements are also possible in cereals until crop stand height of 40 cm. Measurements were conducted at different soil water contents, therefore the question raised to which extent this might influence absolute values of electrical conductivity and whether the specific EC_a pattern may seasonally vary. For this investigation, a field site of 89 ha in size was chosen which was mapped in April 1999 at increased soil water contents and in September 2000 at drier soil conditions. Values from the different dates correlated closely with each other (r^2=0.88; FIGURE 2).

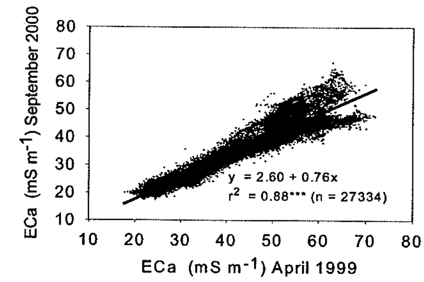

Figure 2. Relationship between bi-temporal measurements of EC_a

Values from September were slightly lower (0-15 mS m^{-1} depending on the soil substrate) than in April. Low soil water contents reduce EC_a values. Results from this site as well as from other multi-temporal measurements show that the pattern of the electrical conductivity does not strongly vary. Measurements can be conducted throughout the year, but are preferably conducted at field capacity.

Comparison of EC_a information with the national soil inventory

Correlation coefficients of linear regression between the apparent electrical conductivity and soil values of the German national soil inventory (Bodenzahlen) varied on eleven different fields in four different regions between r^2=0.01-0.71 (TABLE 1). For the Wulfen site, with highly heterogeneous fields and a wide range of EC_a r^2-values ranged between 0.31-0.71, except on one rather homogeneous site. The range of EC_a in Kassow was much smaller than in Wulfen. Information available from this old data source is interesting, but suffers from several shortcomings. The number of auger holes with detailed soil description varied between n=8-43. EC_a measurements proved to be much better in delineating zones of different soil substrates than the rather subjective delineating indicated by the National soil inventory. This is depicted in FIGURE 3.

TABLE 1. Correlation coefficients of linear regression (r^2) between EC_a and soil values of the German national soil inventory (Bodenzahlen) in four farm sites with different field plots. Significance levels and the number of available soil information on each site are indicated.

Location	Fields				
Wulfen	Finkenherd Pilsenhöhe $0.49^{n.s.}$ (n=8)	Mühlbreite $0.09^{n.s.}$ (n=10)	Wu641/632 0.71*** (n=9)	Dornbock 0.31*** (n=43)	 0.53* (n=11)
Thumby	Ottenkamp 0.33** (n=20)	Alt-Grünholz $0.18^{n.s.}$ (n=9)			
Kassow	104 0.29** (n=25)	106 0.17* (n=25)	107 0.23** (n=29)	111 $0.01^{n.s.}$ (n=19)	
Queis	Bullenstall 0.50** (n=14)				

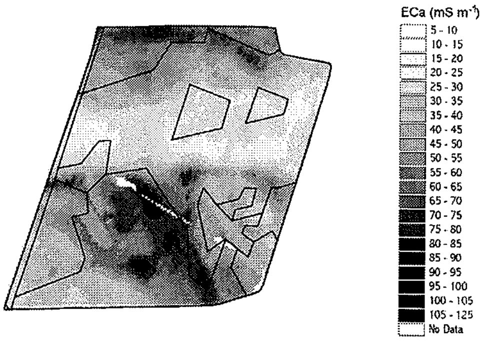

FIGURE 3. Zones of different soil units as indicated by the previously existing national soil inventory (polygons) drawn on a map of the electrical conductivity.

Comparison of the apparent electrical conductivity with yield maps

Comparisons of EC_a to yield were conducted on five different fields at Wulfen. Except one fairly homogeneous field with respect to yield, a fairly good correlation could be found as demonstrated for field site 231 in FIGURE 4 with r^2=0.71***. The analysis is still on-going and will be extended to other sites. In the investigated region water is a limiting factor. This causes that soil heterogeneity is clearly reflected in yield maps. Under such conditions EC_a measurements can represent a very valuable tool to mechanistically indicate soil-borne factors which are yield limiting.

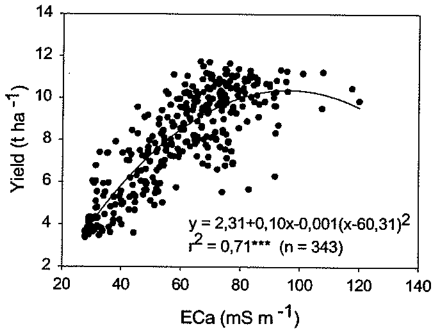

FIGURE 4. Relationship between yield and EC_a from a field site in Wulfen.

Electrical conductivity versus information from airborne remote imagery
The normalised differential vegetation index retrieved from airborne multispectral remote imagery and EC_a (FIGURE 5) correlated with each other (r^2=0.47***). NDVI data were obtained from a flight campaign in 2000 with a Daedalus scanner. The investigated site is characterised by a rather stable yield pattern over the years.

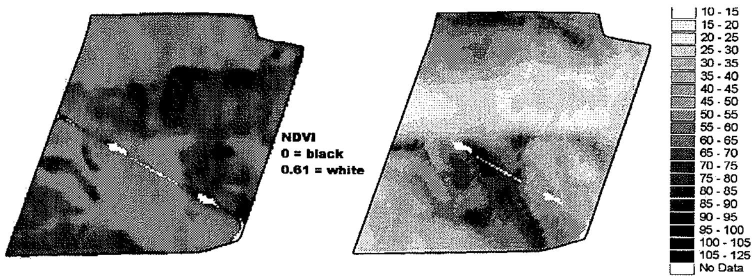

FIGURE 5. Maps of NDVI and EC_a from heterogeneous field site in Wulfen

CONCLUSIONS

The information obtained from electromagnetic induction offers an interesting approach to map soil heterogeneity. Maps of EC_a are fairly time-invariant throughout the year which means that mapping could be conducted at any time of the year or in any year. The interpretation of the information is fairly straightforward as compared to other sources of spatial information e.g. from yield maps or remote sensing imagery and does not require measurements over several years. Yield may be closely related to soil-borne factors and thus to maps of EC_a measurements. Alternatively the weather influence may mask this relationship which calls for a more sophisticated approach by combining static soil information with weather scenarios.

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