AgEng
BUDAPEST 2002

EurAgEng

Paper Number: 02-PA-004

Title:

Mapping within-field soil variability for precision agriculture using electromagnetic induction

Authors:

Hanquet, B.(*); Frankinet, M.; Parez, V.; Destain, M.-F.

Department of Agricultural Engineering, Gembloux Agricultural University,
Passage des Déportés 2, B-5030 Gembloux, Belgium.
Tel: +32 (0)81 622163 Fax: +32 (0)81 622167 e-mail: hanquet.b@fsagx.ac.be

Summary:

Among the crops production factors, the soil is obviously one of the most important. Therefore, within the context of Precision Agriculture, the spatial variability knowledge of its physical and chemical properties is essential as a decision support information for cultural operations modulation.

The purpose of this study is to assess the capability of electromagnetic induction sensing of apparent electrical conductivity (ECa) for the characterisation of within-field variability of soil physical and/or chemical properties in the particular soil conditions encountered in our experimental area, namely non-saline deep silty soils.

ECa maps were produced on a 7ha field in April 2001, September 2001 and April 2002. Concurrently, an intensive soil survey (112 points) was carried out in February 2001 in order to determine a series of physical, textural and chemical soil parameters. ECa accurately described clay content, and exchangeable K and Ca cations concentrations.

1. Introduction

Precision Agriculture aims at adapting cultural practices in accordance with field variability in order to precisely meet the crops needs. This optimal management of agricultural soils implies the assessment of their fertility potential and of their capability of producing and supporting crops. As a consequence, the knowledge of soil physical and chemical properties at field scale appears as an essential factor in the decision process governing such management strategy.

Up to now, data collection on soil is mostly made by grid sampling. Measurements of these properties are labour-intensive, time-consuming and expensive. Because of this, the development of sensors suited to quantify soil properties at the scale required for accurately mapping within-field variations appears as a necessity in order that Precision Agriculture can be widely practised (Stafford, 2000).

On-line measurement of soil electrical conductivity (EC) appears as an efficient solution for delineating soil condition at field scale. Sensors performing these measurements can be classified in two types: they are based or contacting or non-contacting methods. Sudduth *et al.* (1999) obtained soil EC data with an non-contact sensor based on electromagnetic induction principles (Geonics EM38, Geonics Ltd., Mississauga, Ontario) and compared it with data from a direct contact, coulter-based sensor (Veris 3100, Veris Technologies, Salina, Kansas). They concluded that differences in EC measurements can be attributed to differences in sensing depth between the sensors and their operating modes.

Soil EC is mainly affected by the following parameters: soil salinity, clay content and water content (Rhoades *et al.*, 1989). Several studies have shown the usefulness of soil apparent electrical conductivity (ECa) measurement for soil physical and chemical properties determination. Williams and Hoey (1987) showed that ECa can be interpreted in terms of average salt content and average clay content on 15 m depth, in saline, multi-layered soil profiles. Kachanoski et al. (1988) found that the spatial variation of soil water content in the top 0.5 m was highly correlated to ECa readings in a soil with low concentrations of dissolved electrolytes. Durlesser and Stanjek (1997) showed that ECa allows to map within-field variations of clay content (German soil containing between 18 and 30 percent clay). Sudduth *et al.* (1999) linked the ECa measurements to topsoil depth in claypan soils. Kitchen *et al.* (2000) found significant relationships between base cations (Ca, Mg and K) and ECa on Mississippi delta soils. Hartsock *et al.* (2000) achieved similar results from a study conducted in Kentucky. Waine *et al.* (2000) used ECa measurements to produce maps of available water content. Auerswald *et al.* (2001) established a model predicting ECa, based on clay content, electrical conductivity of the soil solution and water content.

2. Purpose

The purpose of this study is to assess the capability of electromagnetic induction sensing of ECa for the characterisation of within-field variability of soil physical and/or chemical properties in the particular soil conditions encountered in our experimental area, namely non-saline deep silty soils. This study was prefaced with a comparison of EMI measurements with classical resistivity measurements by means of a geo-electrical survey on a transect, in order to ensure validation of EMI sensing method.

3. Materials and methods

3.1. Study site

The experiment was conducted on two sites located near Gembloux (Belgium). This region is situated on the low and feebly undulating plateaux, to the west of the Belgian “silty area”.

3.1.1. Transect measurements

The first part of this study, consisting in concomitant measurements of ECa using two different techniques, took place on a transect, in the border of a fallow field. Soil is classified as alluvial, moderately gleyed soil on silt (Adp, in the Belgian classification) (Pécrot, 1957).

3.1.2. Field measurements

Continuous ECa measurements were performed on a 7 ha field (see Fig. 1a). In the centre part of the field, soils are classified as deep silty soils (Aba and AbB), while in the southern and in the northwestern part, soils are alluvial, well drained soils on silt (Abp, light tones on Fig. 1b) (Pécrot, 1957). Slope varies between 0 and 6 %. During cultural seasons 2001 and 2002, this field was covered by winter wheat crops.

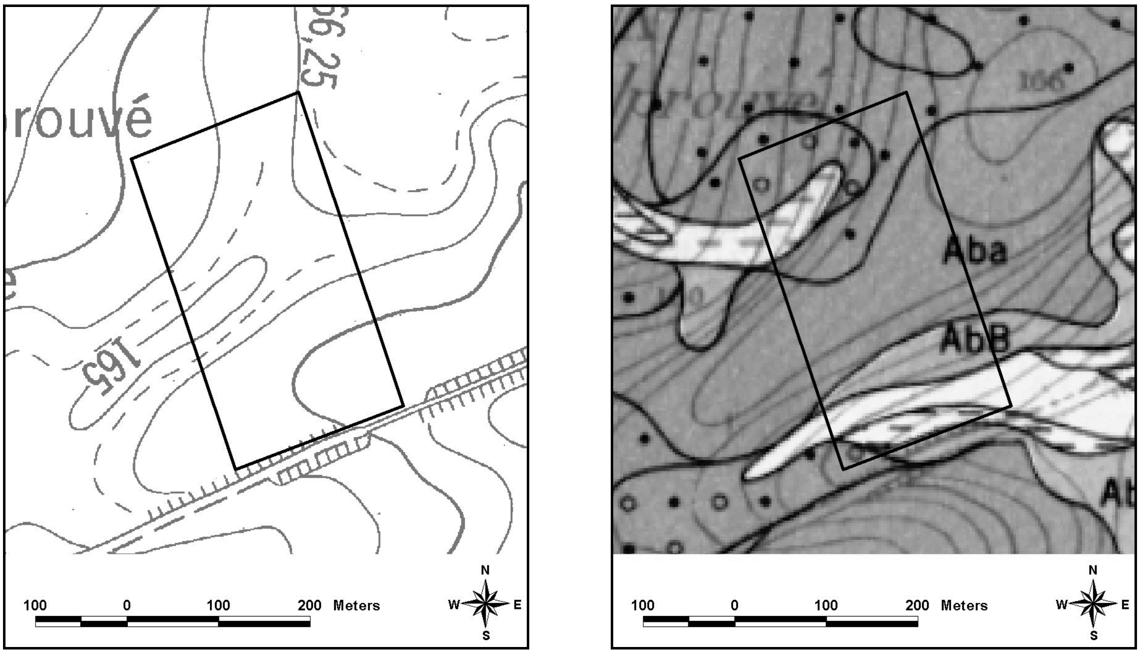

Fig. 1. Experimental field, (a) topographic (contour lines interval : 2.5 m) and (b) pedological maps

3.2. Soil electrical conductivity measurement

The sensor used in the framework of this study is the Geonics EM38 (Geonics Limited, Ontario, Canada). This sensor uses electromagnetic induction (EMI) principle. This soil apparent electrical conductivity (ECa) sensing method has the advantage of allowing field measurement, without any soil perturbation and without taking soil samples. The EM38 can be operated in two different modes: in vertical or in horizontal dipole position. Each mode results in a different investigation depth: the soil depth on which the electrical conductivity measurement is integrated is approximately 1.5 m in vertical mode (ECV), while in horizontal mode (ECH), this depth is about 0.75 m.

3.3. Validation of EMI measurements

Concomitant measurements of soil electrical resistivity and soil electrical conductivity were performed respectively by means of geo-electrical measurements and EMI technique. These measurements were done on 8th of June 2001, along a 260 m transect located in the border of a fallow field. Measurement interval is 10 m.

3.3.1. Geo-electrical survey

The principle of this method consists in injecting a current of known intensity between two electrodes A and B inserted in the soil. The potential created in this way is influenced by the resistivity of the constituting materials of the soil and is sensed with two different electrodes M and N.

Two configuration were used: "Wenner α" were the order of the electrodes is AMNB and "Wenner γ" were the electrodes are arranged in the order AMBN. The distance *a* separating two neighbouring electrodes defines the investigation depth. The effective investigation depths z_{ie} for each configuration are:

"Wenner α" : $z_{ie} = 0.52$ a "Wenner γ" : $z_{ie} = 0.59$ a

Measurements were performed on the 26 points of the transect, using both electrodes configurations, with 2 gaps (1 m and 2 m). Consequently, effective investigation depths are: 0.5 m, 0.6 m, 1 m and 1.2 m.

3.3.2. EMI measurements

Measurements were done on the 26 points of the transect, also on 4 different investigation depths, approximately equal to the ones obtained with the geo-electrical measurements: 0.5 m, 0.6 m, 1 m and 1.2 m. In order to achieve this, measurements were done in ECV and ECH modes and placing the instrument at two different height above the ground surface.

3.4. Soil electrical conductivity mapping

In order to perform on-line field measurements, the Geonics EM38 was mounted on a specially constructed, tractor-pulled cart. The cart is entirely made of wood in order to avoid interference that would arise from metallic parts close to the sensor (see Figure 2).

Fig. 2. Wooden cart supporting the Geonics EM38 for continuous measurement: (a) overall picture, (b) detail.

Moreover, the design of the cart ensured a constant height of the sensor above the soil during operation and the possibility of doing measurements in both modes of operation (ECV and ECH). The DGPS localisation (Omnistar 3100-LR-12) guaranteed an accurate localisation of EM38 measurements. The combined acquisition of the signals (EM38 and DGPS) was made by means of a LabView (National Instruments) self-made virtual instrument.

The first ECa measurements, on the 5th of April 2001, were done without the cart. An operator caried the sensor along tracks in the field. Therefore, these data are less accurate than those acquired with the cart on 11th of September 2001 and on 10th of April 2002 (better localisation and constant sensor height). All ECa measurements were done in vertical mode.

3.5. Soil physical and chemical properties measurements

3.5.1. Transect measurements

Soil moisture content was measured on each point of the transect on 1 m depth. Soil samples were collected on 4 layers (0 to 25 cm, 25 to 50 cm, 50 to 75 cm and 75 cm to 1 m) and water content was determined by gravimetric method.

3.5.2. Field measurements

The determination of soil chemical properties on the experimental field was done by an intensive soil sampling on 12th of February 2001. Soil samples on the top 30 cm were collected at each node of a 25 x 25 m square grid (112 sampling points). A complete textural and chemical analysis was performed in order to determine the following parameters: volumetric percentage of sand, silt and clay, exchangeable sodium (Na), potassium (K), calcium (Ca), magnesium (Mg), and phosphate, organic matter content, pH, total nitrogen and total carbon.

Concurrently with ECa measurements, soil water content was determined in 12 to 18 reference points. On 5th of April 2001, measurements were done on the first 30 cm layer, in 12 reference points. On 11th of September 2001, measurements were done on 4 layers (in 12 points): 0 to 25 cm, 25 to 50 cm, 50 to 75 cm and 75 cm to 1 m. On 10th of April 2002, measurements were done in 18 points on the first 10 cm. These water content measurements were performed by soil sampling and gravimetric method on the two first dates. For the latter experiment, soil moisture content was measured *in situ* using a portable sensor (Theta-Probe ML2x plugged to a Theta-Meter HH1, Delta-T Devices, U.K.).

3.6. Data interpolation and statistical analysis

In order to produce continuous maps representing the within-field variation of soil properties and soil ECa, these were interpolated by means of Inverse Distance Weighted algorithm available on the Spatial Analyst module for ArcView (ESRI). Different search radius depending on the density of the measurements were used to interpolate: 20 m for soil ECa, 30 m for other parameters. An influence factor of 1 was chosen in order to obtain smooth aspect maps. The cell size for all maps is 2 m.

On the other hand, statistical analysis was performed by means of Minitab software to compute matrices of correlation coefficients, linear and multi-linear regressions.

4. Results and discussion

4.1. Validation of EMI measurements

Figure 3 presents the evolution of ECa measured by geo-electrical (investigation depth = 1.0 m) and EMI (1.1 m) techniques. Both profiles showed very similar trends.

The correlation coefficient between the two series is 0.94. Absolute values, however, presented notable differences. These differences can be attributed to the investigation depths of each sensing method, which are purely theoretical. Consequently, the volume of soil which is sensed may be different. Moreover, small disturbances may appear with the geo-electrical method when the contact between the electrodes and the soil is not optimal.

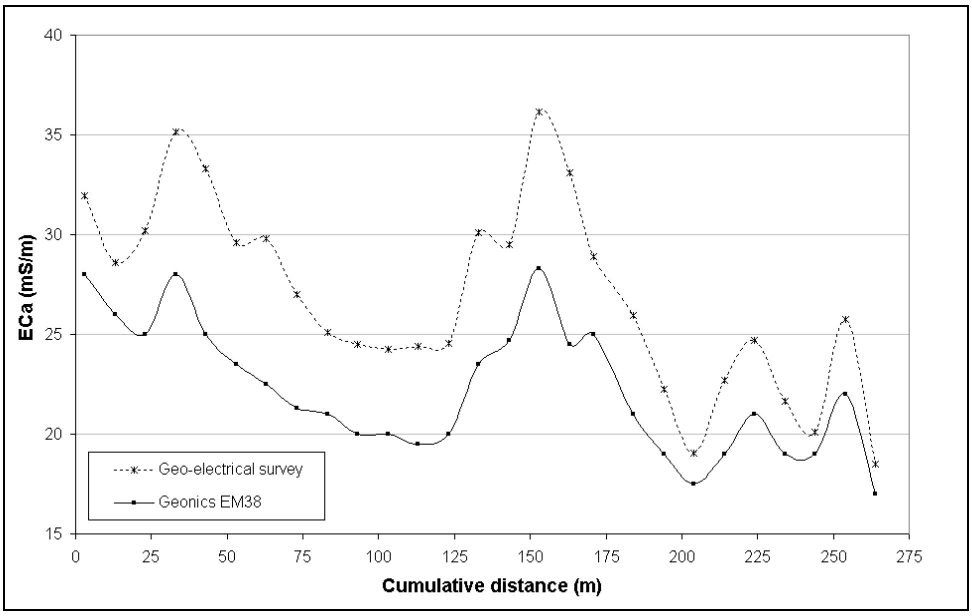

Fig. 3. Comparison of measurements made with the Geonics EM38 and a geo-electrical survey. Evolution of soil water content along the profile.

The good correlation with the proven method of geo-electrical measurement ensures the reliability of EMI technique for measuring soil ECa.

4.2. Soil electrical conductivity mapping

Figure 4 shows the three ECa maps from April 2001, September 2001 and April 2002. These maps indicate that the spatial repartition of high and low ECa values was quite constant in time. Table 1 gives the statistical values of the interpolated ECa data.

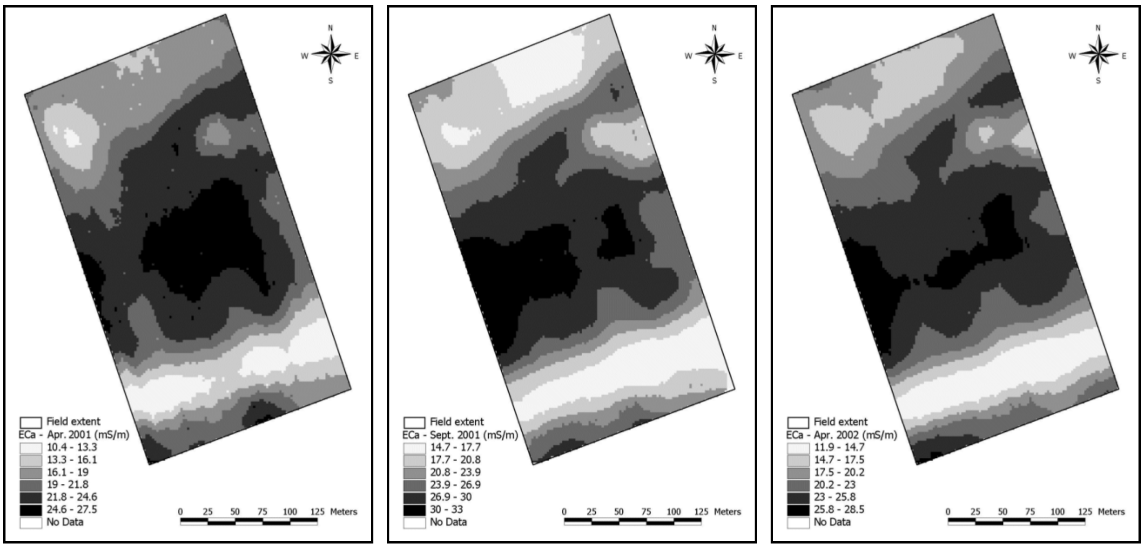

Fig. 4. Interpolated ECa maps. (a) April 2001, (b) September 2001, (c) April 2002.

Table 1 : Statistical values of interpolated ECa values (n = 17626).

	Mean (mS/m)	Std.-Dev. (mS/m)	Min. (mS/m)	Max. (mS/m)
Apr. 2001	20.2	3.9	10.4	27.5
Sept. 2001	23.9	4.9	14.7	33.0
Apr. 2002	21.1	3.9	11.9	28.5

The comparison of these maps with the soil map (Fig. 1) reveals a certain correspondence of low ECa zones with alluvial soils (depressions), while Aba and AbB series present higher values.

4.3. Soil physical and chemical properties measurements

4.3.1. Textural and chemical properties

Figure 5 shows maps for three parameters (among the textural and chemical properties that were determined) cited in the literature, which may explain part of the ECa spatial variability, namely exchangeable K and Ca and clay content. Comparing these three maps to the ECa maps (Fig. 2) reveals some similarity, particularly for clay content.

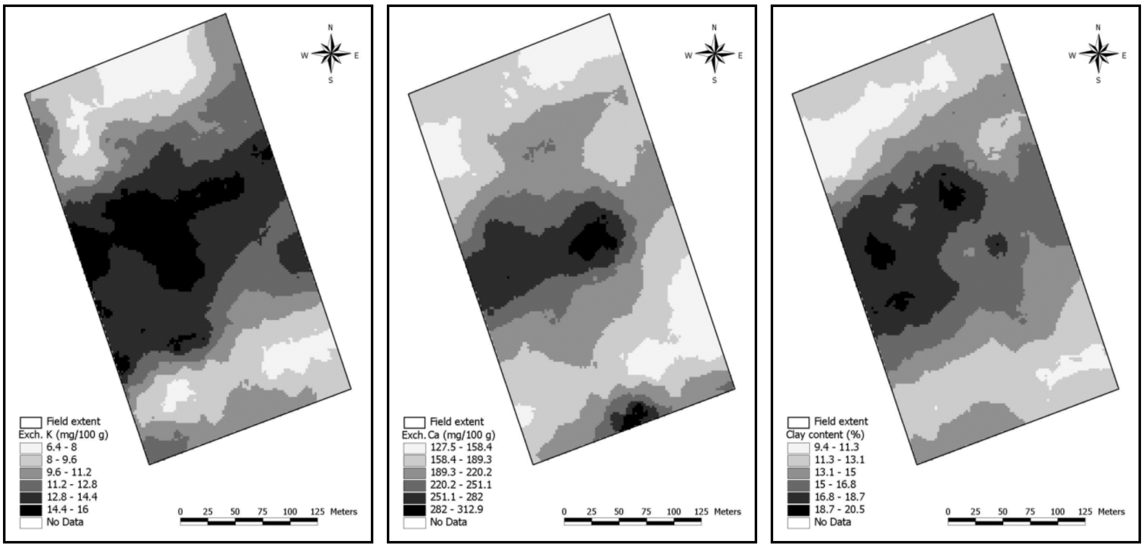

Fig. 5. (a) Exchangeable K map, (b) Exchangeable Ca map, (c) Clay content map.

4.3.2. Moisture content

Table 2 shows the mean values for gravimetric moisture content of the top soil layer (Apr. 2001: 30 cm; Sept. 2001: 25 cm; Apr. 2002: 10 cm).

Table 2 : Mean values for moisture content.

	Apr. 2001	Sept. 2001	Apr. 2002
Number of meas. points	12	12	18
Measurement depth	0 - 30 cm	0 - 25 cm	0 - 10 cm
Soil water content (gr gr^{-1})	0.203	0.174	0.117

Soil moisture content values for April 2002 appear much lower than for the two first dates. Actually, it must be recalled that these measurements were performed with a Theta-Probe sensor in the 0-10 cm depth superficial layer which undergoes much evaporation than the lower layers. Nevertheless, the moisture values can be used to study spatial variability of this parameter in the field at one measurement date.

4.4. Relationships between soil electrical conductivity and physical and chemical properties

The correlation coefficients between ECa, soil texture and chemical parameters were computed on the basis of the 112 points data set. Table 3 gives these *r* values for each ECa measurement date.

Table 3 : Correlation coefficients between ECa and textural and chemical parameters (n = 112).

	Correlation coefficients *r*		
	Apr. 2001	Sept. 2001	Apr. 2002
Clay	0.74	0.85	0.79
Silt	-0.55	-0.70	-0.61
Sand	-0.68	-0.70	-0.70
pH	0.42	0.41	0.40
Organic matter	0.19	0.21	0.18
Exch. P	-0.04	-0.03	-0.08
Exch. K	0.80	0.85	0.83
Exch. Mg	0.39	0.35	0.36
Exch. Na	-0.08	-0.08	-0.04
Exch. Ca	0.70	0.74	0.69
Tot. N	0.20	0.22	0.23
Tot. C	-0.32	-0.33	-0.37

In the experiment conditions, three factors mainly explained ECa variability: clay content, exchangeable K and Ca. Kitchen *et al.* (1998) found good correlation between ECa and Ca and Mg cations (and with K to a lesser extent). No evident relationship with Mg is shown through our data; however, we found a higher correlation with K. The correlation between ECa and clay content is high. Although some authors (Brus *et al.*, 1992; Waine *et al.*, 2000) found highest correlation when the profile humidity is near field capacity, the best correlation was found in September 2001, when the soil moisture is expected to be lower. However, the moisture conditions for all the three dates are distinctly below field capacity, which is approximately 0.25 gr gr^{-1}.

These observations confirm the sensitivity of soil ECa measurements to clay content, and K and Ca cations.

Table 4 : Correlation coefficients between ECa and soil moisture content.

	Correlation coefficients *r*		
	Apr. 2001	Sept. 2001	Apr. 2002
Soil water content (gr gr^{-1})	-0.20	-0.29	-0.89

Table 4 gives the correlation coefficients between ECa an soil moisture content. Relationships for the two first dates are not significant. The high *r* value for April 2002 could not be interpreted, since its negative sign is indicative of an inverse proportionality.

5. Conclusions

This study was carried out in Belgium, to the west of the “silty area”, characterised by non-saline deep silty soils. Electromagnetic induction (EMI) measurements of soil apparent electrical conductivity (ECa) were validated on a transect by means of the comparison with “classical” geo-electrical measurements. The correlation coefficient between the data was 0.94.

A wooden cart was designed for allowing continuous ECa measurements on field. A coupled DGPS ensured the accurate positioning of measured data. ECa measurements were performed three times on one year. Soil ECa revealed to be temporally variable, but the spatial pattern was quite constant.

The use of ECa as an indicator for clay content and exchangeable K and Ca cations was assessed by the correlation of mutli-temporal ECa maps and a very intensive soil survey. Results indicated that ECa allows to map within-field variability for these parameters. Further investigations have to be made in order to get a better insight on the influence of soil water content on ECa measurements. This experiment underlined that a big amount of reference measurements is essential in order to understand relationships linking ECa and soil properties.

6. Acknowledgements and disclaimer

The Belgian Ministry of Small Trade and Agriculture is gratefully acknowledged for financial support of this research. Mention of trade names or commercial products is solely for the purpose of providing specific information and does not imply recommendation or endorsement of the authors.

7. References

Auerswald, K., Simon, S., Stanjek, H., 2001. Influence of soil properties on electrical conductivity under humid water regimes. Soil Sci. 166 (6), 382-390.

Brus, D.J., Knotters, W.A., van Dooremolen, W.A., van Kernebeek, P., van Seeters, R.M.J., 1992. The use of electromagnetic measurements of apparent soil electrical conductivity to predict the boulder clay depth. Geoderma 55, 79-93.

Durlesser, H., Stanjek, J., 1997. Capability and limits of a DGPS supported EM38 survey for the fast estimation of the spatial variation of clay and water content of soils. *In* Field Screening Europe. Gottlieb J. *et al.* (eds.). Wolters Kluwer, Dordrecht, pp. 73-76.

Hartsock, N. J., Mueller, T. G., Thomas, G. W., Barnhisel, R. I., Wells K. L., Shearer, S. A., 2000. Soil electrical conductivity variability. *In:* P.C. Robert *et al.* (ed.) Proc. 5th International Conference on Precision Agriculture. ASA Misc. Publ., ASA, CSSA, and SSSA, Madison, WI.

Kachanoski, R.G., Gregorich, E.G., Van Wesenbeeck, I.J., 1988. Estimating spatial variations of soil water content using noncontacting electromagnetic inductive methods. Can. J. Soil Sci. 68, 715-722.

Kitchen, N.R., Sudduth, K.A., Drummond, S.T., 2000. Characterizing soil physical and chemical properties influencing crop yield using soil electrical conductivity. *In* Proceedings of the Second International Geospatial Information in Agriculture and Forestry Conference, Lake Buena Vista, Florida, 10-12 January 2000.

Pécrot, A., 1957. Carte des sols de la Belgique et texte explicatif de planchette de Gembloux (130 E). Centre de Cartographie des Sols. IRSIA. Belgium.

Rhoades, J.D., Manteghi, N.A., Shouse, P.J., Alves, W.J., 1989. Soil electrical conductivity and soil salinity: new formulations and calibrations. Soil Sci. Soc. Am. J. 53, 433-439.

Stafford, J.V., 2000. Implementing Precision Agriculture in the 21st Century. Keynote paper. AgEng2000, 2-7 July 2000, Warwick.

Sudduth, K.A., Kitchen, N.R., Drummond, S.T., 1999. Soil conductivity sensing on claypan soils: comparison of electromagnetic induction and direct methods. *In* Robert, P.C., Rust, R.H. (eds.), Proceedings of the fourth International Conference of Precision Agriculture, St. Paul, Minnesota, USA, 19-22 July 1998. Part A and Part B. pp. 979-990.

Sudduth, K.A., Drummond, S.T., Kitchen, N.R., 2001. Accuracy issues in electromagnetic induction sensing of soil electrical conductivity for precision agriculture. Comput. Electron. Agric. 31, 239-264.

Waine, T.W., Blackmore, B.S., Godwin, RJ., 2000. Mapping available water content and estimating soil textural class using electro-magnetic induction. European Conference on Agricultural Engineering – AgEng 2000, Warwick, U.K. Paper Number 00-SW-044.

Williams, B.G., Hoey, D., 1987. The use of electromagnetic induction to detect the spatial variability of the salt and clay contents of soils. Aust. J. Soil Res. 25, 21-27.