Research of correlation between electric soil conductivity and yield based on the use of GPS technology

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Abstract: A contact method was used for the continuous measuring of soil electric conductivity using a six disc electrodes apparatus. The placement of the electrodes was chosen on the basis of the depth of the profiles surveyed: 0–0.3 and 0–0.9 m. Two Crop Research Institute fields and two private Farma Dolejšová fields were followed in 2004 and 2005. For the treatment of the EC data obtained and of other information, the tools of geostatistic were applied. Arc View GIS software and its module Geostatistical analyst were used for the analysis of the geo-data obtained and for the elaboration of the soil conductivity and crop yield maps. Four variogram models were tested. Geostatistical analyses make relatively rigorous demands on wide-sense stationarity or at least average stationarity. The selection of any one of the four geostatistical variogram models did not affect the final maps. Exponential model is recommended. The experiments documented a correlation between the two EC profiles investigated but no correlation was found between EC and the yield of crop. Every field and every property has its own characteristic surface which does not correspond with other ones.

Keywords: soil electric conductivity; precision farming; soil properties; geostatistic

Efficient and accurate methods of measuring within-field variations in soil properties are important for precision agriculture (Bullock & Bullock 2000). The apparent profile soil electrical conductivity is one sensor-based measurement that can provide an indirect indicator of the important soil physical and chemical properties.

Soil salinity, clay content, cation exchange capacity (CEC), clay mineralogy, soil pore size and distribution, soil moisture content, and temperature all affect EC (McNeill 1992; Rhoades *et al.* 1999).

In saline soil most of the variations in EC can be related to the salt concentration (Williams & Baker 1982). In non saline soils, conductivity variations are primarily a function of soil texture, moisture content, and CEC (Rhoades *et al.* 1976; Kachanoski *et al.* 1988). Rhoades *et al.* (1989) modeled EC as a function of soil water content (both the mobile and the immobile fractions), the electrical conductivity (EC) of the soil water, soil bulk density, and EC of the soil solid phase.

The measurements of EC can be used for providing indirect measures of the soil properties listed above if the contributions of other soil properties affecting the EC measurement are known or can be estimated. If the EC changes due to one soil property are much greater than those attributable to other factors, then EC can be calibrated as a direct measurement of that dominant factor. Lesch *et al.* (1995a, b) used this direct-calibration approach to quantify the variations in soil salinity in a field where the water content, bulk density, and other soil properties were reasonably homogeneous.

The mapped EC measurements were found to be related to a number of soil properties of interest in precision agriculture, including soil water content (Sheets & Hendrickx 1995), clay content (Williams & Hoey 1987), CEC, and exchangeable Ca and Mg (McBride *et al.* 1990). Because EC integrates texture and moisture availability, two soil characteristics that affect productivity, it can help to interpret spatial grain yield variations, at least in certain soils (Jaynes *et al.* 1993; Sudduth *et al.* 1995; Kitchen *et al.* 1999). Other uses of EC in precision agriculture include refining the boundaries of the soil map units and creating subfield management zones (Fraisse *et al.* 2001).

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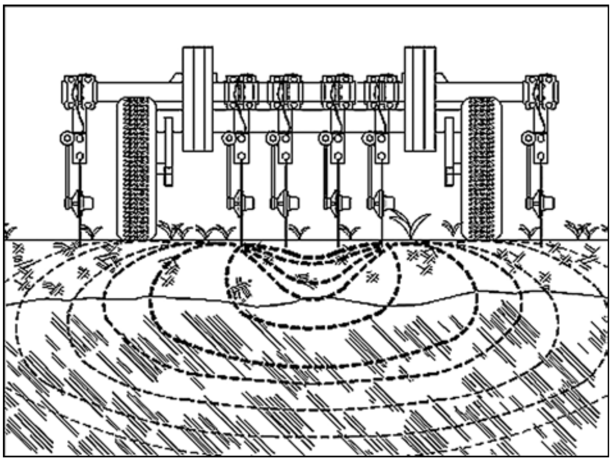

Figure 1. Scheme of coulter-electrodes Milsom (1989)

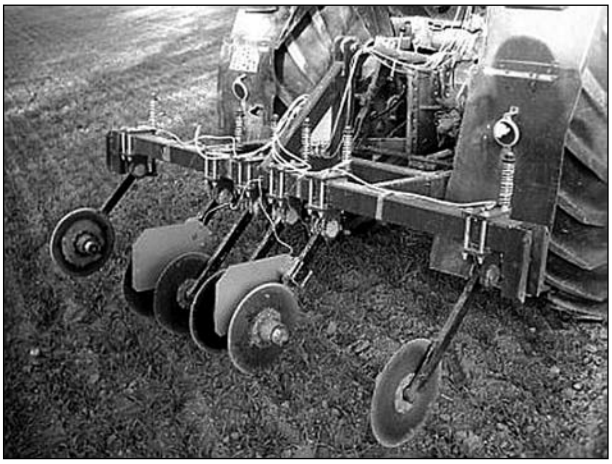

Figure 2. Measuring equipment constructed by Department of Machinery Utilization, Faculty of Engineering

MATERIAL AND METHODS

A contact method was used for the continuous measuring of soil electric conductivity. This type of method uses electrodes, usually in the shape of coulters, that make a contact with the soil to measure the electrical conductivity.

It was preceded by an apparatus with six disc electrodes (Figures 1, 2). This equipment is designed to join with the tractor three-point hanger, so that its sensors – circular electrodes – may be in an uninterrupted contact with soil. The placement of electrodes was chosen on the basis of the depth of the profiles surveyed: 0–0.3 and 0–0.9 m. In this approach, two to three pairs of coulters are mounted on a tool bar; one pair applies electrical current into the soil while the other two pairs of coulters measure the voltage drop between them. The soil EC information is recorded in a data logger along with GPS location information.

The resistivity meter involves applying a voltage into the ground through metal electrodes and measuring the resistance to the flow of the electric current. An AC-power source supplies current flow (I) between the two outer electrodes and the resultant voltage difference (V) between the two inner electrodes is measured.

The resistance of the soil is given by $R = V/I$. This needs to be standardized over the unit length. The

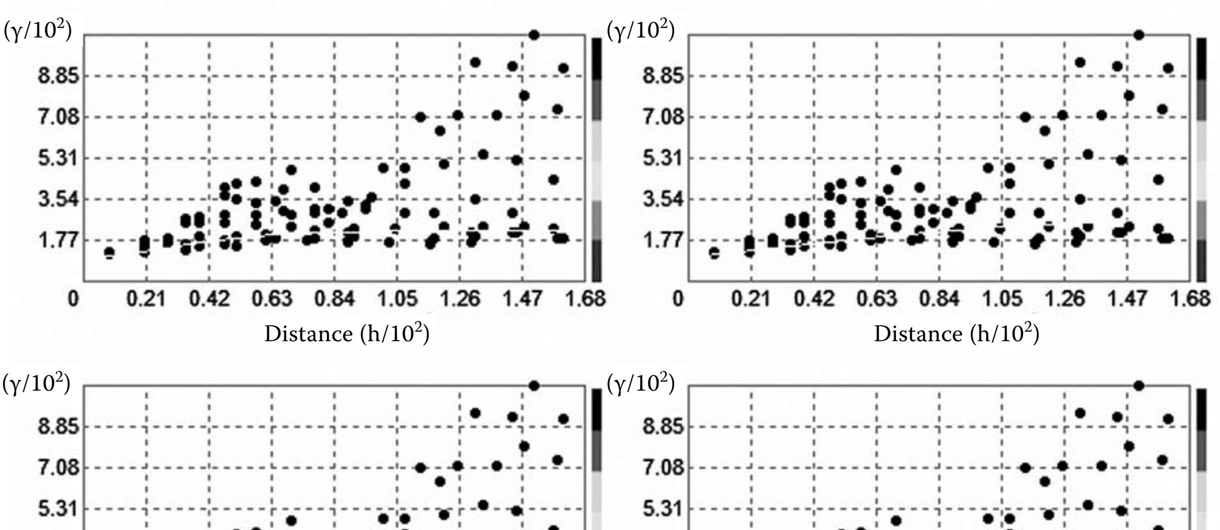

Figure 3. EC semivariograms – k Hostivici (14. 4. 2004, profile 0.3 m)

Table 1. Measured and analysed EC data – Crop Research Institute

		Field			
Date		"k Hostivici" (16 ha)		"u Mostu" (12 ha)	
	profile (m)	0.3	0.9	0.3	0.9
14. 4. 2004	rows of data	1 118	1 118	771	771
	minimum (mS/m)	43.963	20.473	30.894	17.151
	maximum (mS/m)	132.63	83.032	126.22	64.946
	delta max–min	88.667	62.559	95.326	47.795
	average	75.167	49.828	54.417	37.364
	stand. error	13.408	10.303	13.476	8.676
	median	73.687	50.131	51.532	36.925
	scewness	0.79207	–0.15408	2.116	0.3469
	kurtosis	4.3035	2.9709	9.488	2.774
1. 9. 2004	rows of data	1 363	1 363	928	928
	minimum (mS/m)	14.062	6.043	33.664	6.806
	maximum (mS/m)	125.26	35.752	176.73	42.969
	delta max–min	111.198	29.709	143.066	36.163
	average	66.778	21.022	87.079	20.136
	stand. error	18.501	4.55	27.487	5.3178
	median	67.711	21.169	79.724	19.448
	scewness	–0.0891	-0.0505	0.5852	0.6899
	kurtosis	2.8994	2.9269	2.6269	4.376
7. 9. 2005	rows of data	623	623	446	446
	minimum (mS/m)	0.858	0.36487	0.813	0.30065
	maximum (mS/m)	90.666	31.904	223.14	24.626
	delta max–min	89.808	31.53913	222.327	24.32535
	average	15.494	8.266	63.85	7.325
	stand. error	14.761	6.842	67.172	5.9094
	median	10.391	6.338	18.079	6.123
	scewness	1.7567	0.9211	0.496	0.70284
	kurtosis	6.8891	3.0101	1.4996	2.6749

Table 2. Analysed yield data (16. 8. 2004) – Crop Research Institute

	Field	
	"k Hostivici" (16 ha)	"u Mostu" (12 ha)
Rows of data	22 128	10 404
Minimum (t/ha)	2.3558	2.2909
Maximum (t/ha)	12.284	6.9518
Delta max–min	9.9282	4.6609
Average	7.6716	3.8436
Stand. Error	9.8867	7.381
Median	7.6942	3.7901
Scewness	–0.17848	0.555
Kurtosis	5.792	3.492

resistance multiplied by the length (of the resistor in this case the soil) is called the resistivity (r) which is measured in ohm.m. The equation is:

$$r = 2\pi d\, R = 2\pi d\, V/I$$

where:

d – the spacing between the electrodes (m)

Alternatively, this can be expressed in terms of conductance ($C = 1/R$, $\Omega^{-1} = \mathrm{S}$) and conductivity ($c = 1/r$, $\Omega^{-1}/\mathrm{m} = \mathrm{S/m}$). The equation for the (soil electrical) conductivity (EC) is given by:

$$c = 1/(2.\ \pi d\, R) = I/(2.\ \pi d\, V) \quad (\mathrm{S/m}).$$

Electrodes have been replaced by rotating discs which are placed directly into the soil. As the cart

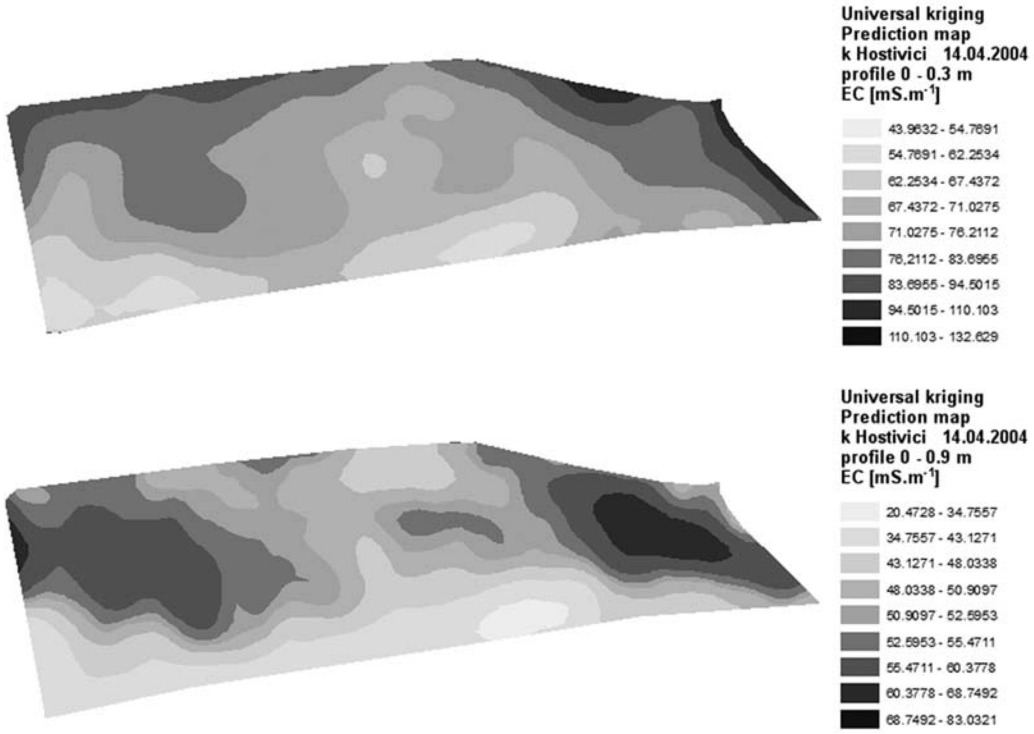

Figure 4. EC maps – both profiles – k Hostivici (14. 4. 2004)

is pulled through the field, one pair of electrodes passes electrical current into the soil, while two other pairs of electrodes measure the voltage drop.

The data of corn yields were obtained from the owners with no information about raw data measuring or analysing.

Investigated fields

The data were collected from two Crop Research Institute fields and two private Farma Dolejšová fields. Crop Research Institute (CRI) fields: "k Hostivici" – 16 ha, "u Mostu" – 12 ha

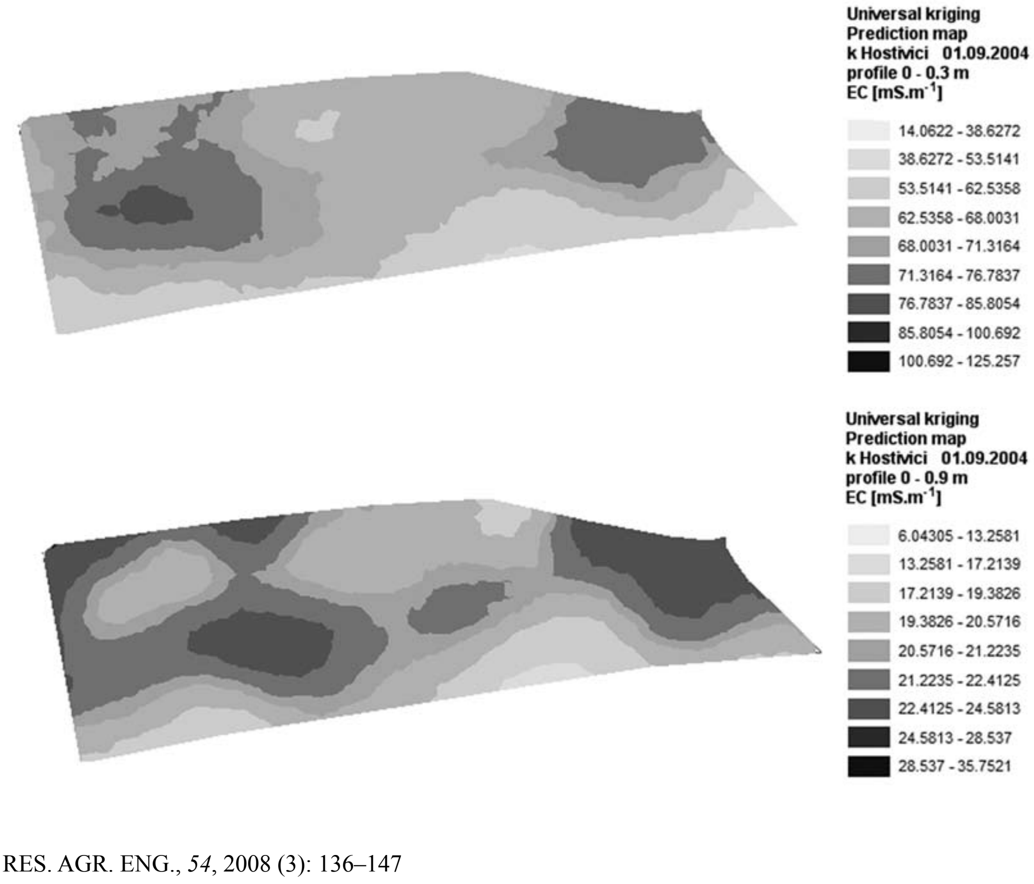

Figure 5. EC maps – both profiles - k Hostivici (1. 9. 2004)

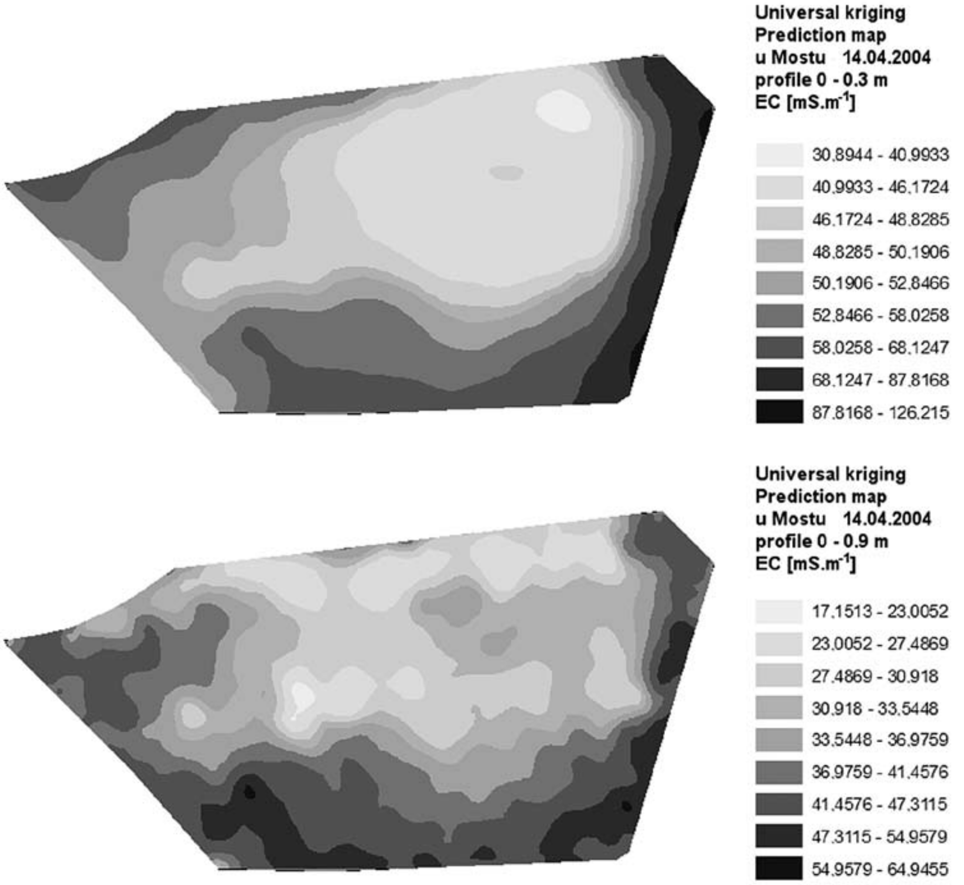

Figure 6. EC maps – both profiles – u Mostu (14. 4. 2004)

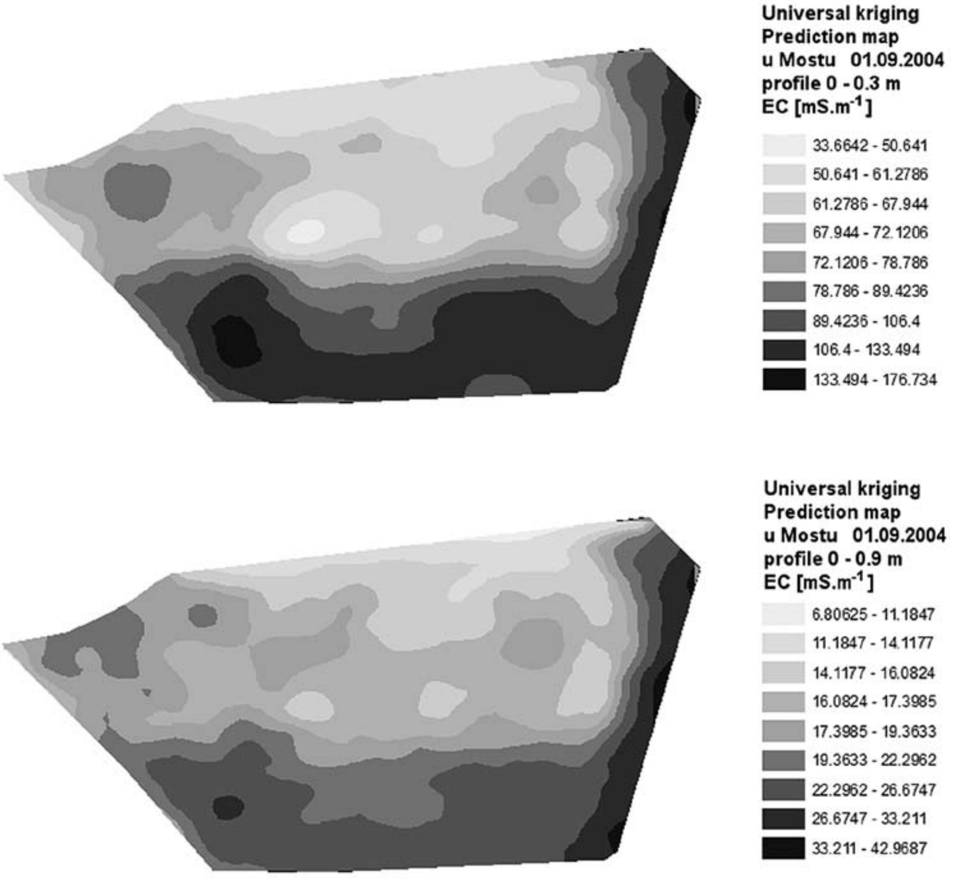

Figure 7. EC maps – both profiles – u Mostu (1. 9. 2004)

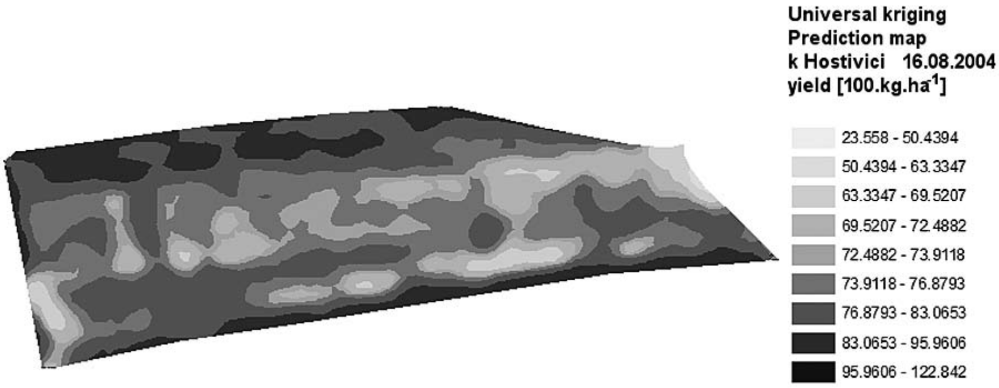

Figure 8. Yield map – k Hostivici (16. 8. 2004)

Dolejšová fields: "Dlouhé" – 8.73 ha, "u Háje" – 13.65 ha.

The measured and analysed EC data from the Crop Research Institute fields are shown in Table 1, while Table 2 shows the measured and analysed data of the crop yield.

The data were measured once during the spring of 2004 and twice in the autumn of 2004 and 2005. The soil moisture conditions were relatively dry at the time of the data collection in both sites in the autumn. Due to this fact the measuring process was not going well as lots of rows (data sentences) went out. The situation is more favourable in springs because a lot of winter water is present in the soil.

ArcView GIS software and its module Geostatistical analyst were used to analyse the geo-data measured and to create the soil electric conductivity and crop yield maps. Four variogram models were tested to this aim. Semivariograms of each model are show in Figure 3.

Figure 3 shows the variograms of four models which were used. The variogram shows the relations between the distance and the values of two adjacent places measured. Similarly, all pictures demonstrate that no significant differences can be recognised. The same conclusion may be made with every analysed data for both profiles of EC and even the crop yield. It is recommended to use the most widely used exponential variogram models.

The EC maps of k Hostivici field, 0.3 m profile on the left side, 0.9 m profile on the right side, are shown in Figures 4 and 5.

The EC maps of u Mostu field, 0.3 m profile on the left side, 0.9 m profile on the right side, are shown in Figures 6 and 7.

The simplest and fastest way to interpret a soil EC map is to compare it visually to the yield or soil survey maps of the same field. A more rigorous analysis would involve rasterisation of the EC data and yield monitor data into square grid cells that are consistent with each other. The average EC values from the grid cells can be compared to the yield values from the corresponding cells using linear regression and other statistical techniques.

The grop yield maps of both fields in CRI are shown in Figures 8 and 9.

At first sight, it is easy to see that the maps of both profiles of EC data are similar even through the year

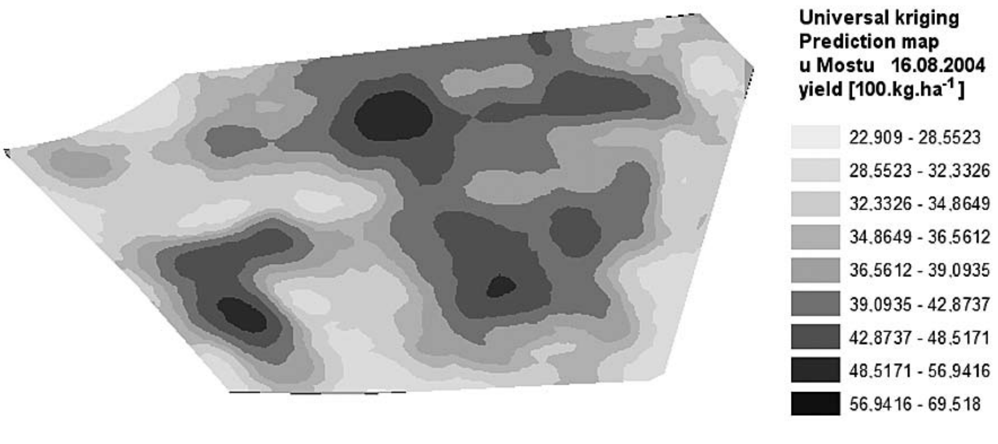

Figure 9. Yield map – u Mostu (16. 8. 2004)

Table 3. Measured and analysed EC data – Dolejšová

Date		Field			
		"Dlouhé" (8.73 ha)		"u Háje" (13.65 ha)	
	profile (m)	0.3	0.9	0.3	0.9
13. 5. 2004	rows of data	721	721	837	837
	minimum (mS/m)	29.95	8.7127	29.992	12.497
	maximum (mS/m)	83.192	59.097	93.153	47.724
	delta max–min	53.242	50.3843	63.161	35.227
	average	45.598	33.915	46.978	32.367
	stand. error	8.1203	5.9761	9.9583	4.2221
	median	44.123	32.895	44.941	31.924
	scewness	1.0356	1.0799	1.511	0.29038
	kurtosis	4.5686	6.4636	5.8181	4.9793
2. 9. 2004	rows of data	948	948	1 302	1 302
	minimum (mS/m)	13.921	5.6139	16.364	7.4248
	maximum (mS/m)	117.11	32.669	108.64	34.8
	delta max–min	103.189	27.0551	92.276	27.3752
	average	59.905	17.554	65.451	19.73
	stand. error	17.268	4.0215	11.913	3.6825
	median	58.155	17.2	66.019	19.315
	scewness	0.3566	0.44711	–0.3361	0.6431
	kurtosis	3.5015	3.691	4.3904	4.3968

Table 4. Analysed yield data – Dolejšová

Year		Field	
		"Dlouhé" (8.73 ha)	"u Háje" (13.65 ha)
2004	date	1. 8. 2004	3. 8. 2004
	rows of data	4 168	6 414
	minimum (t/ha)	2.468	2.32
	maximum (t/ha)	8.485	8.258
	delta max–min	6.017	5.938
	average	5.7372	5.7355
	stand. error	0.86268	0.9844
	median	5.588	5.925
	scewness	–0.74678	–0.93055
	kurtosis	5.2524	3.8648
2005	date	27.8.2005	27.8.2005
	rows of data	4 168	6 414
	minimum (t/ha)	2.468	2.32
	maximum (t/ha)	8.485	8.258
	delta max–min	6.017	5.938
	average	5.7372	5.7355
	stand. error	0.86268	0.9844
	median	5.588	5.925
	scewness	–0.74678	–0.93055
	kurtosis	5.2524	3.8648

and in both fields as well. But no surface similarity between the EC and yields maps was recognised in either field.

The measured and analysed EC data from Dolejšová fields are shown in Table 3 while Table 4 shows the measured and analysed data of the crop yield.

The EC maps of Dlouhé field, 0.3 m profile on the left side, 0.9 m profile on the right side, are shown in Figures 10 and 11.

The crop yield maps from years 2004 and 2005 of Dlouhé field are shown in Figure 12.

The EC maps of u Háje field, 0.3 m profile on the left side, 0.9 m profile on the right side follows (Figures 13, 14).

The crop yield maps from 2004 and 2005 of u Háje field are shown in Figure 15.

There are some facts shown by Dolejšová maps like those on CRI fields the maps of EC data from both profiles are rather similar, no matter if the data were obtained in spring or in autumn. Maximums and minimums are in the same places (have the same locations). But they are rather different from the yield maps. No correlation exists between the EC and the crop yield maps.

More sophisticated statistical methods are available to evaluate the spatial and mathematical simi-

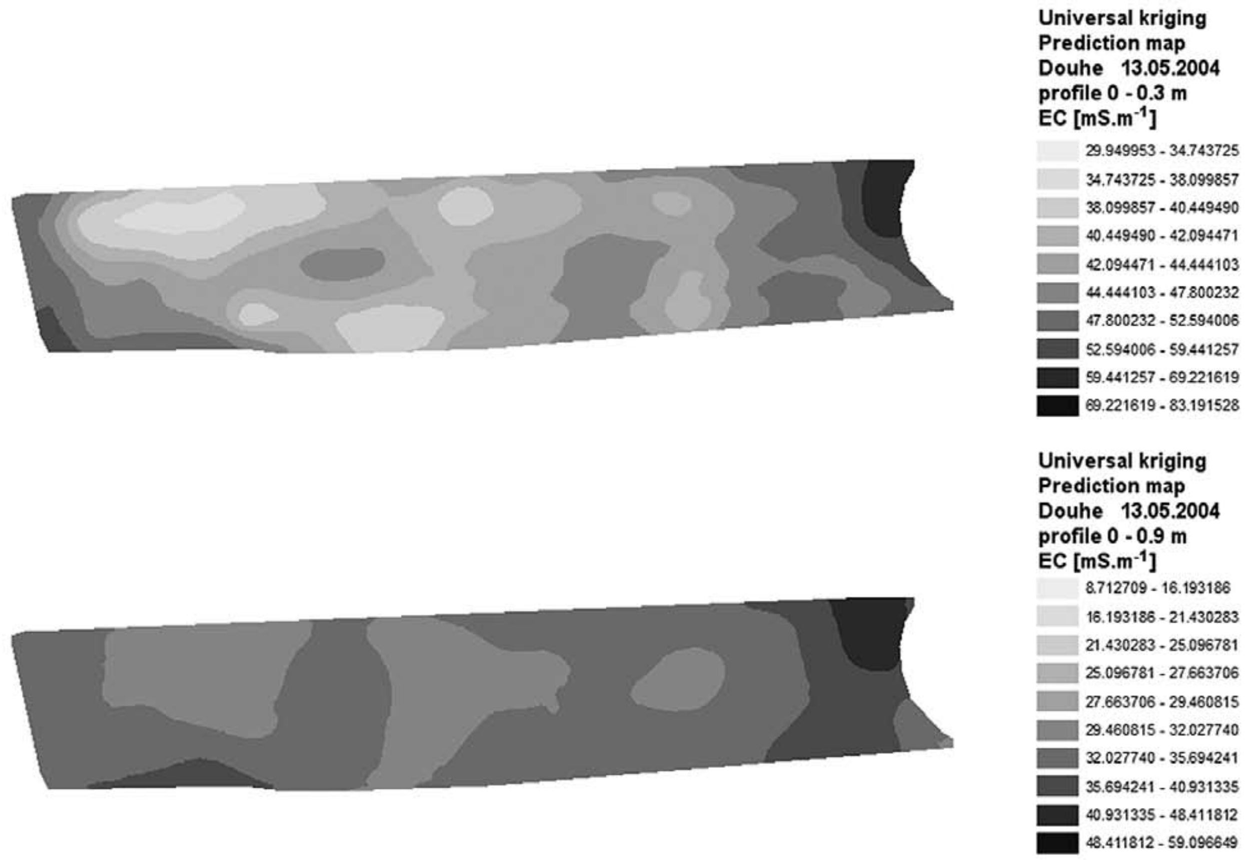

Figure 10. EC maps – both profiles – Dlouhé (2. 9. 2004)

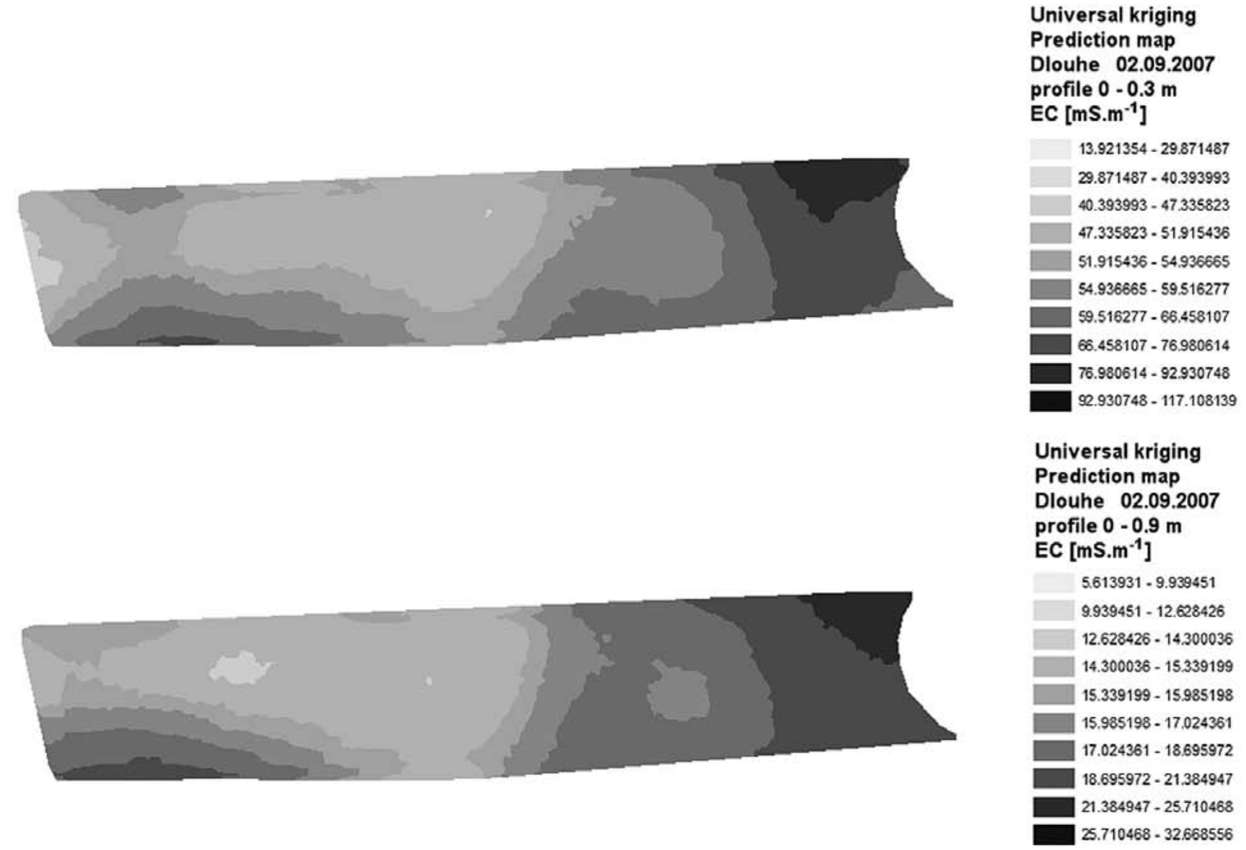

Figure 11. EC maps – both profiles – Dlouhé (13. 5. 2004)

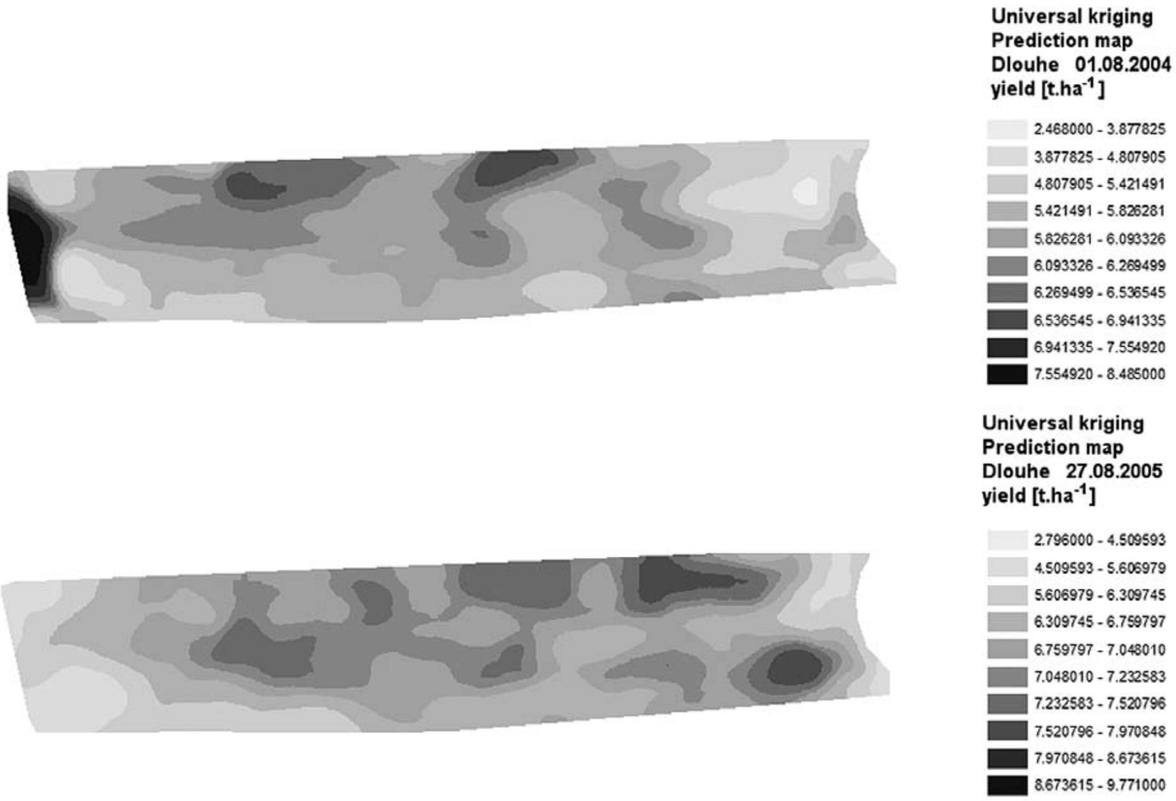

Figure 12. Yield maps – Dlouhé (1. 8. 2004 and 27. 8. 2005)

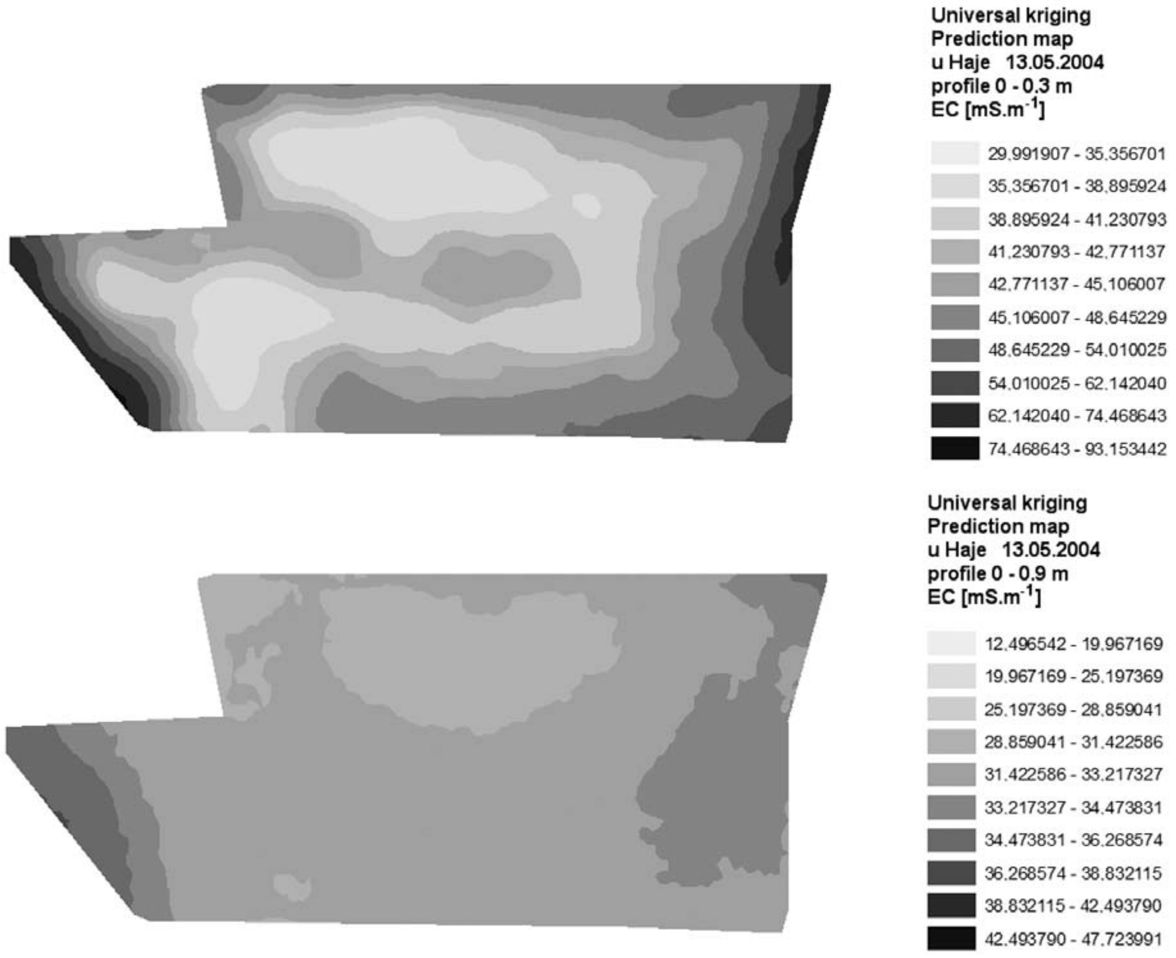

Figure 13. EC maps – both profiles – u Háje (13. 5. 2004)

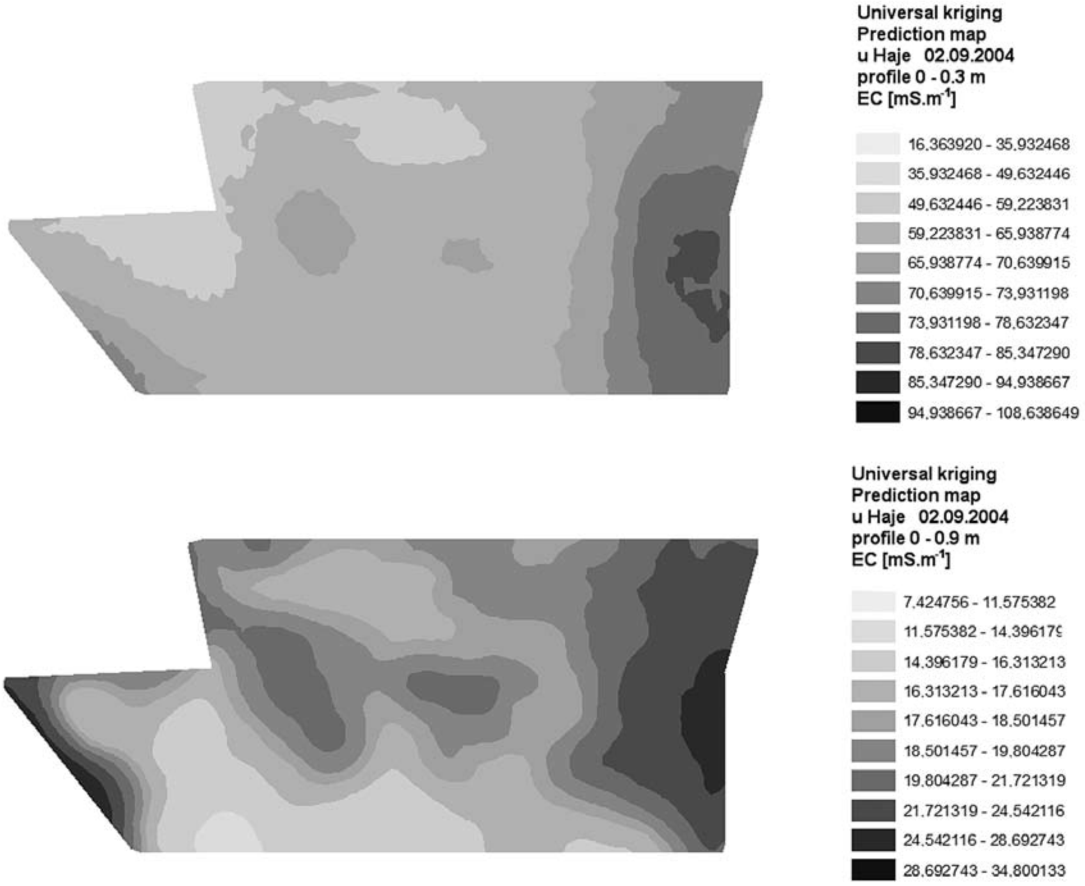

Figure 14. EC maps – both profiles – u Háje (2. 9. 2004)

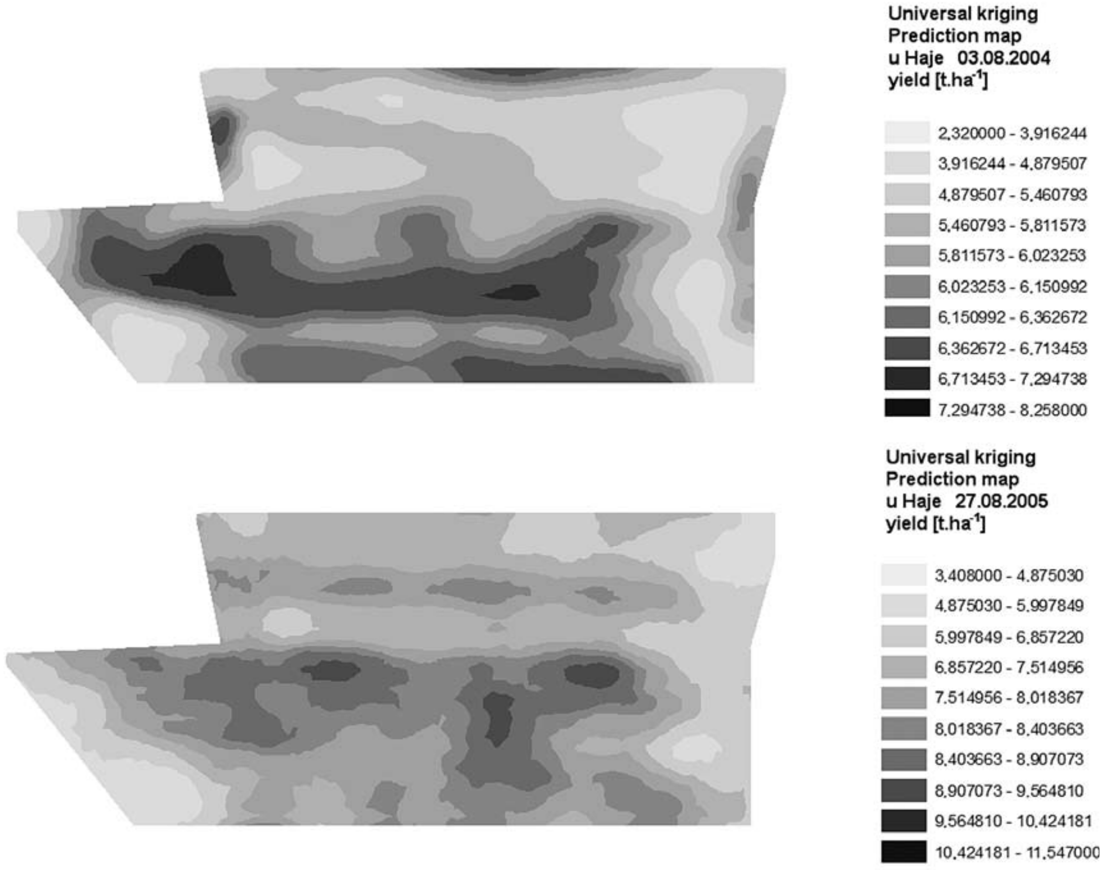

Figure 15. Yield maps – u Háje (3. 8. 2004 and 27. 8. 2005)

larities between different layers including multivariate clustering (Lark *et al.* 1997), multifractal and autoregressive state-space analysis (Wendroth *et al.* 1999). These techniques are current research tools that may be included in future generations of precision farming software and crop simulation models.

DISCUSSION

The utility of EC mapping comes from the relationships that frequently exist between EC and a variety of other soil properties that are highly related to the crop productivity. These include such properties as water holding capacity (dry soil conductivity is much lower than that of moist soil), topsoil depth, soil nutrient levels and cation exchange capacity (CEC – presence of Ca, Mg, K, Na in the moisture-filled soil pores will enhance soil EC in the same way as salinity does), salinity (increasing concentrations of electrolytes (salts) in soil water will dramatically increase soil EC), soil drainage, organic matter level, and subsoil characteristics.

Using the soil electric conductivity measuring technology will differ from grower to grower and from region to region due to the differences in the soil characteristics, growers' needs and interests, and users' expertise in utilising the spatial data. For some uses, the grower or data analyst will need the access to a moderately powerful GIS rather than just simple yield mapping software. Private consultants and mapping centers will be needed to assist with EC mapping and analysis.

SUMMARY AND CONCLUSIONS

In this paper, the following conclusions are presented. Soil EC has no direct effect on the crop yield. The experiments documented no correlations between EC_{SH} and the crop yield even if the soil properties were indicative of productivity.

The actual conclusions confirmed a correlation between the surveyed profiles of 0.3 m and 0.9 m followed during springs and autumns as well as over the years. A certain relation can be found between the higher values of electric soil conductivity, low pH factors, and the high levels of groundwater present in the field. On the contrary the correlation between conductivity and plant yields was not unconfirmed. It is recommended to continue in the research of EC measuring and in the collection of data on soil properties, and to look for mutual relations and correlations.

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Abstrakt

Ryšan L., Šařec O. (2008): **Výzkum korelace mezi vodivostí půdy a výnosem s využitím technologie GPS.** Res. Agr. Eng., **54**: 136–147.

Pro měření elektrické vodivosti půdy byla použita kontaktní metoda – šesti kotoučový měřící přístroj. Rozmístění elektrod bylo zvoleno podle požadované hloubky zkoumaných profilů: 0,3 m a 0,9 m. Měření probíhala v letech 2004 a 2005 na dvou pozemcích VÚRV Praha-Ruzyně a taktéž dvou pozemcích na soukromé farmě Dolejšová. Pro analýzu a následné zpracování geo-dat a vytvoření map elektrické vodivosti a výnosu byly použity nástroje ArcView GIS a doplňující modul Geostatistical analyst. Relativně přísnou podmínkou pro použití geostatistických analýz je podmínka stacionarity respektive stacionarity druhého řádu. Rozdíly mezi použitím čtyřmi různých modelů variogramů se neprokázaly, zvolené modely neměly zásadní vliv na výsledné mapy. Doporučeno je používání exponenciálního modelu variogramu. Experimenty potvrdily jistý vztah mezi hodnotami EC a oběma zkoumanými profily, naopak se neprokázala korelace mezi elektrickou vodivostí půdy a výnosem. Vytvořené mapy ozřejmily přítomnost charakteristického rysu každého pozemku u všech zkoumaných vlastností, tyto charakteristické rysy jsou pro každý pozemek a každou vlastnost jedinečné.

Klíčová slova: elektrická vodivost půdy; precizní zemědělství; vlastnost půdy; geostatistika

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