



Connection between soil moisture content and electrical conductivity in a precision farming field

ISTVÁN BALLA¹ – GÁBOR MILICS² – JÓZSEF DEÁKVÁRI³ – LÁSZLÓ FENYVESI³ –
NORBERT SMUK² – MIKLÓS NEMÉNYI² – MÁRTON JOLÁNKAI¹

¹ Szent István University
Institute of Crop Production
Gödöllő

² University of West Hungary
Institute of Biosystems Engineering
Mosonmagyaróvár

³ Ministry of Rural Development
Hungarian Institute of Agricultural Engineering
Gödöllő

SUMMARY

Field measurements were carried out for investigating soil moisture content and electrical conductivity measurements in a precision farming field near Mosonmagyaróvár, Hungary. On the field site-specific crop production had been applied since 2001. The measuring instruments were as follows: 1. A 20 cm long rod Spectrum Field Scout TDR-300 soil moisture meter equipped with a data logger and GPS was used to detect the soil moisture content (MC) in 0–20 cm depth of the study field. 2. A vehicle-pulled Veris-3100 Electrical Conductivity (EC) meter equipped with GPS-connection as well.

We analysed and find correlation between TDR-300 soil moisture and Veris-3100 electrical conductivity data on the investigated field in the given circumstances after crop harvest in 2009.

The found strong correlation ($R^2 = 0.7897$) of soil moisture content and apparent soil electrical conductivity data may provide information about the soil moisture content variation in the investigated field, however extrapolation of the found correlation to other soil texture, and moisture status requires further research.

Keywords: precision agriculture, soil moisture content, specific Electrical Conductivity, TDR 300, Veris 3100.

INTRODUCTION AND LITERATURE REVIEW

Crop production is directly related to the temporal and spatial changes of the moisture content of soil. Water as well as nutrients is key factors determining of crop production (Sharma *et al.* 1993). The use of available moisture amount by a crop serves for crop growing. Its actual amount can best be obtained from the accurate soil moisture content distribution in the root zone. However, assessment of spatial distribution of soil moisture content through field measurements is expensive, time consuming and laborious (Sharma *et al.* 1997).

In general grain yields depend on the soil type, crop requirement, amount of precipitation, and soil water-storage capacity (Boone 1988, Lampurlanes *et al.* 2002, Hemmat and Eskandari 2004).

According to Pepó (2009), the amount of grain yield and different agronomic features of wheat are influenced by the ecological (weather, soil), biological (genotype) and agrotechnical (crop rotation, nutrient supply, water supply, plant protection) factors together. Crop yields are influenced primarily by the amount and distribution of precipitation and the soil's capacity to hold moisture (Lawes *et al.* 2009).

Water availability is a major factor that limits grain yield. Due to low and variable rainfall, available water is the most important limiting factor for agricultural production. When available water becomes limited, water deficits are unavoidable in some periods of the crop development (Kang *et al.* 2003).

Crop water use varies substantially during the growing period due to the variation in crop canopy and climatic conditions (Allen *et al.* 1998).

Accordingly, the water management and water resources of the soil have an important role in the mitigation of unfavourable weather effects (especially water shortage) (Shen *et al.* 1999, Domitruk *et al.* 2000).

Štekauerová *et al.* (2006), Nagy *et al.* (2007) and Šútor *et al.* (2009) investigated the water resources of soils at agricultural sites and woodland ecosystems. According to their studies soil moisture content differed in both horizontally and vertically in the given measurement points.

Water management of soil means the amount, state, form and movement of water in soil, and temporal and spatial change of these factors. Besides it includes infiltration, permeability of water, water holding and storage capacity of soil and the conditions of drying (Birkás 2010). The water management of soils is the essential precondition of its fertility, as it influences the air, heat and nutrient management, biological activities and cultivability of soils (Stefanovits 1975).

Precipitation, irrigation water, surface inflow, incoming leakage from the groundwater and incoming underground leakage increase, while evapotranspiration, surface and underground runoff decrease the water resources of soils. In the case of hydrological factors influencing the moisture content of the soil a kind of periodicity can be observed. Both water shortage and drought damages, and damages caused by the excess amount of water can be experienced (Nyiri 1993).

Due to the fact that yields are affected by many factors, it is very difficult to exactly define how the water resource of the soil – being a separate yield influencing factor – influences the yield (Késmárki *et al.* 1993, Palkovits and Schummel 1992).

For keeping the optional moisture conditions in precision agriculture it is essential to accurately map the distribution of soil moisture content in the fields.

In order to replace the measurement of the yield influencing soil parameters – including soil moisture content –, electrical conductivity has been already used by Tao (1998) in precision agriculture experiments.

The future of precision agriculture and natural resource managements rests on the reliability, reproducibility and understanding of the technology developments upon which it is based (Williams and Hoey 1987, Milne 1991, Hartssock *et al.* 2000, Kravchenko and Bullock 2000, Corwin and Lesch 2003, Papp and Fenyvesi 2007, Fenyvesi *et al.* 2008).

Our experiment was a technology development research for investigating connection between measured field soil moisture content and the electrical conductivity of the soil.

MATERIAL AND METHODS

The measurements were carried out in the experimental site of the Institute of Biosystems Engineering, Faculty of Agricultural and Food Sciences of the University of West Hungary near Mosonmagyaróvár. The experimental site is situated in a 23.52 hectares large agricultural field on which precision agriculture has been applied since 2001. The MEPAR (Agricultural Parcel Identification System) code of the field is K2XEW-8-08.

Soil moisture content and electrical conductivity measurements were carried out directly after harvest on the wheat stubble on 28th July 2009. Different soil sampling strategies as well as techniques for soil moisture content measurements and the comparison of the results have been already published by several authors (Rajkai and Rydén 1992, Rajkai 1993, Nagy *et al.* 2008). We used a Spectrum TDR-300 type soil moisture probe for data collection for preparing the soil moisture distribution map of the field. This appliance defines the volumetric soil moisture content based on TDR (Time Domain Reflectometry) measuring principle. According to the manufacturer's description the resolution of parallel measurements is 1%, its accuracy is < 3% in soil moisture content range of 0–50%. Earlier calibration measurements – carried out by the research team – in various soil types have approved the reliability of the device. The soil moisture probe also collects the location coordinates due to an external GPS receiver. The capacity of the built-in memory registers 1350 measurements together with the GPS coordinates, or stores 3250 measurements without GPS coordinates.

The aerial of the GPS device was fixed on top of a pole placed a rucksack together with its power accumulator. We used a long measuring Rod length of the TDR-300 was 20 cm. The rod length defined the sensed soil depth. During the measurement of soil moisture content we were walking throughout the field, and stacked the TDR-300 probe into the soil every 10 meter along the sampling line (see *Figure 3.*), and stored the measured data.

Parallel to the soil moisture measurements the electrical conductivity of the field soil was measured with a Veris-3100 specific electrical conductivity meter (www.veristech.com). Specific electrical conductivity is a material characteristic, it is the reciprocal to the specific resistance.

Important parts of the Veris-3100 meter are the measuring disks (6 pcs) with $\varnothing 430$ mm diameters, which are electrically isolated from other units of the device (*Figure 1*). The arrangement of disks is symmetrical. The appliance measures the specific electrical conductivity of the soil in depths of 0–30 cm and 0–90 cm at the same time. Trimble AgGPS 114 row marker was the GPS receiver operating in differential mode locating the rout at the sensed field. The measured data is stored in every second. The recorded data are saved on a floppy disk.

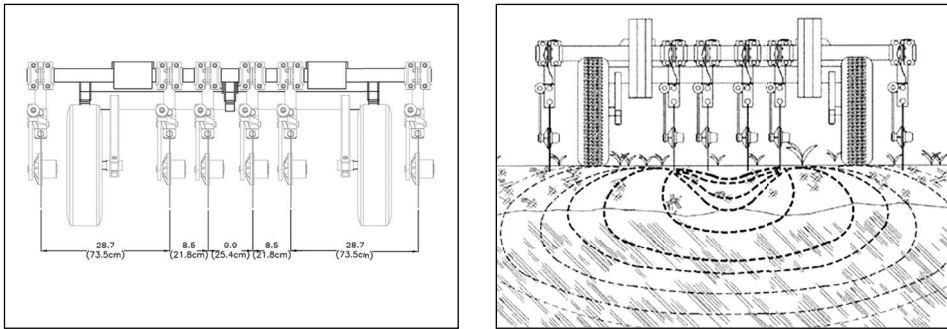


Figure 1. Functional principle and conformation of Veris 3100
Figures are from Veris Technologies (www.veristech.com)

We pulled the Veris-3100 device with a tractor (*Figure 2.*). Tractor speed was 18–20 km/h in time of field measurement. Therefore soil electrical conductivity of the field happened approximately at every fifth meters. The adjusted row distance was 5 m, consequently the measured data were registered approximately in 5x5 m.



Figure 2. Veris 3100 Electrical Conductivity meter in use
Photos: István Balla

The interlinked data of TDR-300 and Veris-3100 devices were statistically analysed by the MINITAB program (Baráth *et al.* 1996). Extreme values were also processed as described by Baráth *et al.* (1996). We defined the first and the third quartiles (Q1, Q3) with the help of the MINITAB program. Between the two values we get the interquartile range (IQR). By these the extreme values are defined subtracting 1.5 IQR from the first quartile value, or adding it to the third quartile value. All registered values below X_{min} or above X_{max} were regarded extreme. The interval between X_{min} and X_{max} was accepted without further restriction. With this method a new data series was generated, without extreme values. Since the used GPSs linked the geographic coordinates of sensed data to WGS84 (World Geodetic System), they had to be converted into the EOVS (Unified National Projection System) coordinate system used in Hungary. For this conversion the EHT² program was used (www.gnssnet.hu). By the ArcGIS ArcMap 9.2 program (www.esri.com) the soil moisture content and electrical conductivity map of the area was made using the Inverse Distance Weighting interpolation method.

For statistical comparison of sensed data values at the same points of the field needed to collect using their geographic coordinates. For this reason 50 circle shape areas with 1 m diameter were appointed in the field. Since in many circles there were no soil moisture content data, larger – 5 m, 10 m, 20 m radius – circles were used.

Moisture content data recorded within the circles were averaged, and the average electrical conductivity data within the same circle were then compared by regression analysis. Choosing the site and the diameter inclusion of adequate amount of sensed data from both measurements was targeted. Consequently, the sample circles were placed along the track of the more densely recorded soil moisture points.

EVALUATION AND DISCUSSION OF THE RESULTS

Sampling sites of the measuring appliances used in the agricultural field is shown in *Figure 3*.

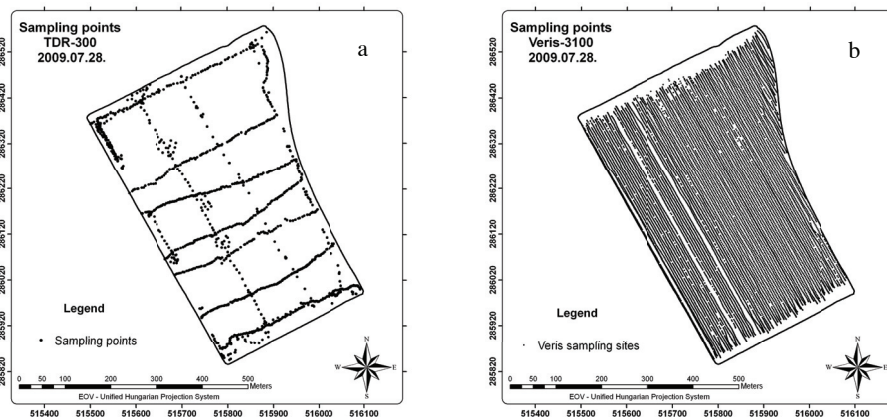


Figure 3. Sampling places of TDR-300 (a) and Veris 3100 (b) at the experimental field

It is clearly visible in *Figure 3*, that the number of soil moisture measuring places (*Figure 3.a*) is a fraction of the number of points scanned by the Veris 3100 device for electrical conductivity. The filtered TDR-300 point data number is 1090, while that of the Veris 3100 is 13230. The electrical conductivity data are rather evenly distributed on the whole field area, while the soil moisture content data are far not. This fact can be traced back to the use of the two appliances. Maps of the measured soil moisture contents (a) and electrical conductivity (b) can be seen in *Figure 4*.

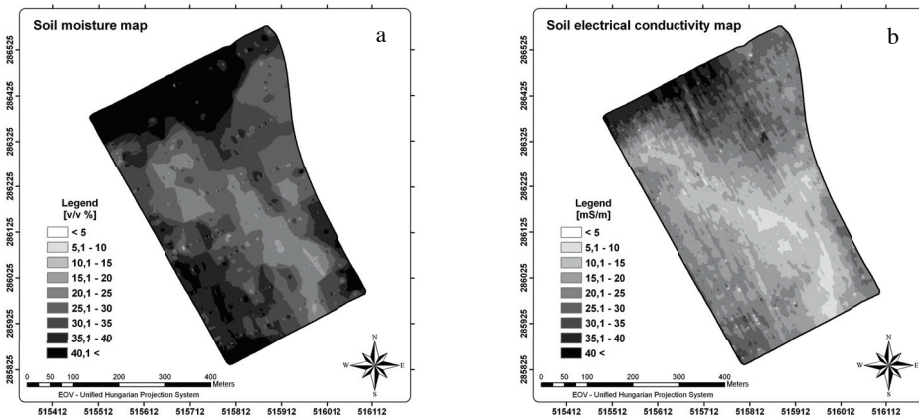


Figure 4. Soil moisture content and electrical conductivity maps of the study field (ArcGIS ArcMap 9.2)

The areal pattern in map (a) and (b) is however rather similar. Maps are created interpolating measured data within 5 m (*Figure 5*). On visible similarity of soil electrical conductivity and moisture content we analyzed their correlation.

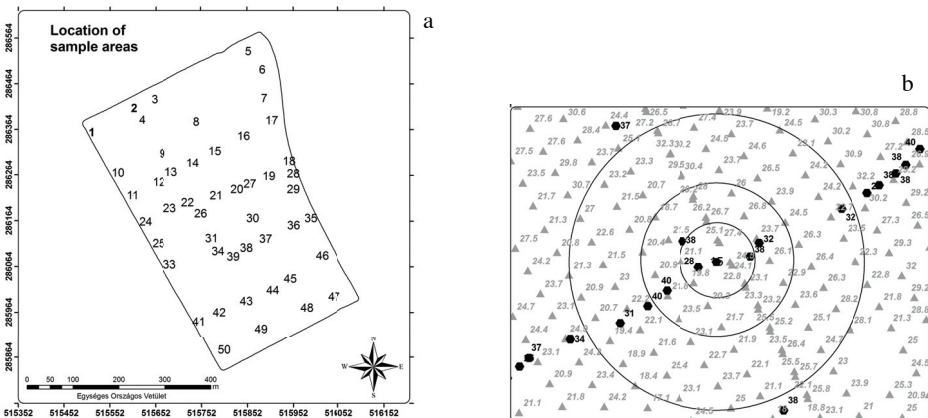


Figure 5. Location of center point of the computational rings (CR) in the study field (a) (note: CR 40 was excluded due to missing data), and 5, 10 and 20 m radius CRs around nr. 36 (b)

Computational rings (CR) locations (a) and an example of their different size expansion is shown in *Figure 6*. For eliminating zero measured moisture content CRs 11 m, 21 m and 41 m diameter CRs were used.

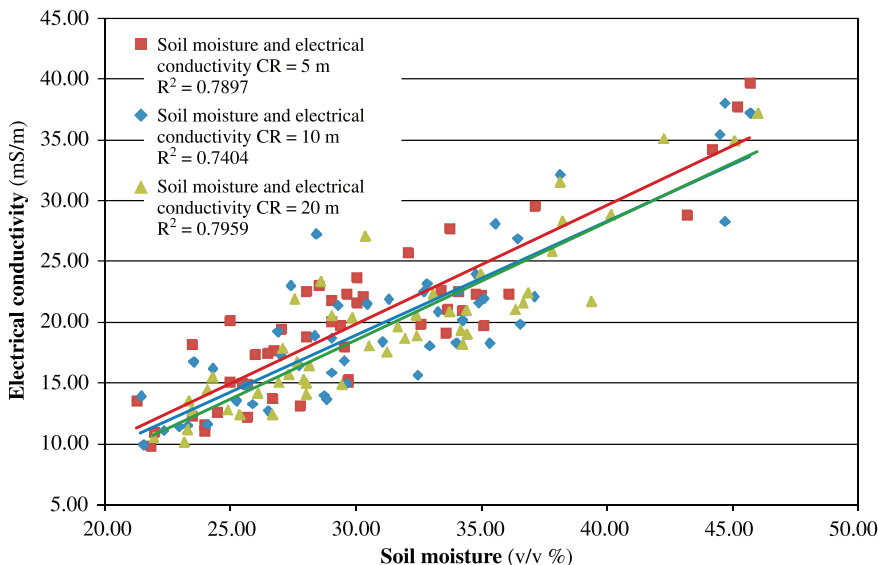


Figure 6. Moisture content and electrical conductivity averages of different diameter computational rings at the 50 locations of the study field

Data used in the statistical analysis are shown in *Table 1.* and *Table 2.* As computational ring no. 40 did not include sufficient number of measured data it was left out.

Average moisture content (MC) and electrical conductivity (EC) data of different diameter CRs are given in *Figure 6*. Linear regression lines for MC and EC of diameter 5, 10 and 20 CRs are drawn as well in *Figure 6*.

Determination coefficient (DC) of soil moisture content and electrical conductivity is fairly strong for the 5 m diameter computational rings ($R^2 = 0.7897$). This area is small, therefore the measured MC and EC data are close, and so, their standard deviation is close to average. DC of 10 m diameter CRs is $R^2 = 0.7404$. The SD of 10 m diameter CRs is larger, that of in 5 m diameter CRs. In case of 20 m diameter CRs DC is the highest ($R^2 = 0.7959$). Although we got the largest standard deviation result here, the correlation between soil moisture content and electrical conductivity is the strongest in this case. Presumably, the reason for this is the higher number of measured data and the average value calculated from them, which is more representative from the point of consequences. In such a large area spatial changes can be more significant both in the positive and in the negative direction. Although the value of standard deviation was larger in this case, probably the average improved the result.

Table 1. Averages of TDR-300 and Veris 3100 measured data in the 1–25 computational rings (CR)

Number of CR	Soil moisture content CR = 5 m	Electrical conductivity CR = 5 m	Soil moisture content CR = 10 m	Electrical conductivity CR = 10 m	Soil moisture content CR = 20 m	Electrical conductivity CR = 20 m
1	44.00	34.21	44.29	35.45	42.08	35.10
2	45.00	37.75	44.50	38.03	44.88	34.91
3	45.50	39.70	45.50	37.24	45.80	37.21
4	43.00	28.80	44.50	28.28	40.00	28.88
5	32.00	25.70	36.33	26.88	37.69	25.88
6	28.00	22.53	29.25	21.38	27.54	21.93
7	29.33	19.75	29.00	18.69	29.80	20.40
8	37.00	29.60	38.00	32.15	38.00	31.55
9	26.00	17.32	24.33	16.18	27.31	15.68
10	34.16	20.95	34.16	20.16	31.60	19.61
11	30.00	21.60	32.75	23.16	33.00	22.36
12	21.33	13.50	21.50	13.91	24.10	14.50
13	23.50	18.14	23.57	16.75	24.31	15.49
14	29.00	21.80	30.40	21.51	29.00	20.55
15	30.00	23.67	34.67	23.98	34.88	23.98
16	28.50	23.03	28.40	27.25	30.33	27.10
17	25.00	20.10	27.40	23.01	28.57	23.40
18	27.00	19.45	26.89	19.23	27.07	17.88
19	26.67	13.70	28.71	13.98	28.00	15.02
20	26.75	17.68	27.00	17.28	27.64	16.73
21	29.67	15.25	29.00	15.85	26.91	15.03
22	23.50	12.28	24.11	11.60	23.50	12.74
23	25.67	12.20	25.88	13.26	23.38	13.51
24	34.91	22.25	33.19	20.87	32.33	20.59
25	34.00	22.47	34.00	22.55	36.25	21.03

Table 2. Average values of TDR-300 and Veris 3100 measurements in the convenient buffer zones (Part 2)

Averages of TDR-300 and Veris 3100 measured data in the 25–50 computational rings (CR)

Number of CR	Soil moisture content CR = 5 m	Electrical conductivity CR = 5 m	Soil moisture content CR = 10 m	Electrical conductivity CR = 10 m	Soil moisture content CR = 20 m	Electrical conductivity CR = 20 m
26	24.00	11.03	23.00	11.41	24.90	12.75
27	34.67	22.30	36.43	19.85	34.33	19.04
28	25.00	15.10	29.60	14.94	27.91	15.29
29	29.50	18.00	28.80	13.66	26.67	12.41
30	22.00	10.97	23.33	11.51	23.33	11.18
31	32.50	19.88	32.86	18.04	31.18	17.55
32	29.60	22.33	31.25	21.89	33.65	20.85
33	30.25	22.14	34.80	21.59	34.32	21.00

continue

Number of CR	Soil moisture content CR = 5 m	Electrical conductivity CR = 5 m	Soil moisture content CR = 10 m	Electrical conductivity CR = 10 m	Soil moisture content CR = 20 m	Electrical conductivity CR = 20 m
34	28.00	18.76	29.50	16.82	28.13	16.40
35	36.00	22.35	37.00	22.11	36.55	21.60
36	24.50	12.57	25.25	13.54	28.00	14.07
37	24.00	11.52	22.40	11.10	22.00	10.51
38	27.75	13.14	26.50	12.72	25.38	12.37
39	25.50	14.98	32.40	15.64	29.40	14.92
41	33.57	21.06	35.00	21.96	36.74	22.40
42	33.33	22.60	32.63	22.53	39.24	21.73
43	29.63	15.04	27.71	16.44	31.88	18.67
44	29.00	20.05	28.33	18.88	30.47	18.03
45	25.67	14.89	25.64	14.80	26.10	14.13
46	26.50	17.45	31.00	18.42	32.35	18.86
47	33.50	19.12	35.23	18.27	34.16	18.18
48	21.88	9.85	21.59	9.94	23.19	10.16
49	35.00	19.71	33.92	18.30	34.08	19.30
50	33.67	27.71	35.45	28.11	38.09	28.36

CONCLUSIONS

As a result, the time-consuming manual sampling can be replaced with the much simpler and faster measuring method, which produces higher sample number, consequently is more representative.

In precision agriculture having accurate information about the habitat is the basic prerequisite of all agricultural activities, as the amount of yield of a specific plant species is influenced by genetic, ecological and production technology factors together, which can change and vary considerably even within one agricultural field according to the micro-habitat conditions. In our experiment we investigated one of the development possibilities of indirect soil moisture measuring, which is one of the most important factors influencing the yield. According to our results, it can be stated that manual soil moisture measuring can be safely replaced with the accurate mapping of the electrical conductivity of the soil. The Veris-3100 specific electrical conductivity meter that we used during our experiment proved that under proper conditions it can be used for defining the moisture content of the soil in the investigated field. It was proven that besides using maps made by geographical information systems, traditional statistical analyses also have to be carried out for the verification of correlations during making comparisons. The problem which encountered during statistical comparison – namely that the TDR-300 probe and the Veris-3100 meter use different coordinate systems for storing their data – was solved by using computational rings having different diameters. Further research is needed to define how the connection between soil moisture content and electrical conductivity changes in the case of the different soil types, physical characters and salinity of the soils.

A talajnedvesség-tartalom és a talajellenállás közötti összefüggés vizsgálata egy precíziós gazdálkodási módszerekkel művelt táblán

BALLA ISTVÁN¹ – MILICS GÁBOR² – DEÁKVÁRI JÓZSEF³ – FENYVESI LÁSZLÓ³ –
SMUK NORBERT² – NEMÉNYI MIKLÓS² – JOLÁNKAI MÁRTON¹

¹ Szent István Egyetem
Növénytermesztési Intézet
Gödöllő

² Nyugat-magyarországi Egyetem
Biológiai Rendszerek Műszaki Intézete
Mosonmagyaróvár

³ Vidékfejlesztési Minisztérium
Mezőgazdasági Gépesítési Intézet
Gödöllő

ÖSSZEFOGLALÁS

Vizsgálataink során a talajnedvesség-tartalom és a talaj elektromos vezetőképessége közötti összefüggést vizsgáltuk egy precíziós módszerekkel művelt mezőgazdasági táblán Mosonmagyaróvár közelében. A területen 2001 óta folyik a precíziós gazdálkodás műszaki eszközeinek vizsgálata. A mérések során a következő mérőeszközöket használtuk: 1: Spectrum Field Scout TDR-300 talajnedvesség-tartalom mérő műszer 20 cm-es tűskékkel ellátva, amelyhez egy kiegészítő GPS-antenna is tartozott. 2: Veris-3100 talaj elektromos vezetőképességét mérő műszer, amely egy vontatott eszköz, szintén GPS antennával kiegészítve.

A mért adatok elemzése során a TDR-300 által mért talajnedvesség (MC) és a Veris-3100 által mért talaj elektromos vezetőképesség (EC) adatok összehasonlítására került sor. A méréseket búzatarlón végeztünk 2009-ben.

A két mérési adatbázis összehasonlítása során erős korrelációt találtunk a két adat között ($R^2=0,7897$), aminek alapján arra a következtetésre jutottunk, hogy a vizsgált táblán a talajnedvesség-tartalom meghatározható a talaj elektromos vezetőképességének mérése alapján. A vizsgálatok további folytatása szükséges annak érdekében, hogy eltérő talajtextúra, illetve eltérő talajtulajdonságokkal rendelkező területek esetén is fennáll-e az összefüggés a két mért érték között.

Kulcsszavak: precíziós gazdálkodás, talajnedvesség-tartalom, talaj elektromos vezetőképesség, TDR-300, Veris-3100.

ACKNOWLEDGEMENTS

The authors thank the Institute of Crop Production of the Szent István University, the Institute of Biosystems Engineering of the University of West Hungary and the Hungarian

Institute of Agricultural Engineering of the Ministry of Rural Development for providing equipment needed for the experiment and for their help.

This research was supported by the European Union and co-financed by the European Social Fund in frame of the project "TALENTUM – Development of the complex condition framework for nursing talented students at the University of West Hungary" project ID: TÁMOP-4.2.2/B-10/1-2010-0018.

Furthermore, the authors thank for the support TÁMOP-4.2.1/B-09/1/KONV-2010-0006 research project.

REFERENCES

- Allen, R. G. – Pereira, L. S. – Raes, D. – Smith, M. (1998): Crop Evapotranspiration – Guidelines for Computing Crop Water Requirements, Irrigation and Drain, Paper No. **56**, FAO, Rome, Italy, 300.
- Baráth Cs. – Ittész A. – Ugrósdý Gy. (1996). Biometria. (Biometric) Mezőgazda Kiadó, Budapest.
- Birkás M. (2010): Talajművelők zsebkönyve. (Pocketbook of tillagers) Mezőgazda Kiadó, Budapest.
- Boone, F. R. (1988): Weather and other environmental factors influencing crop responses to tillage and traffic. *Soil Tillage Res.* **11**, 283–324.
- Corwin, D. L. – Lesch, S. M. (2003): Application of soil electrical conductivity to precision agriculture: theory, principles and guidelines. *Agron J.* **95**, 455–71.
- Domitruk, D. R. – Duggan, B. L. – Fowler, D. B. (2000): Soil water use, biomass accumulation and grain yield of no-till winter wheat on the Canadian prairies. *Canadian Journal of Plant Science.* **80**, (4) 729–738.
- Fenyvesi L. – Deákvári J. – Kovács L. – Papp Z. (2008): Távérzékelési módszerek alkalmazási lehetőségei a mezőgazdaságban. *Mezőgazdasági technika.* **1**, 2–4.
- Hartsock, N. J. – Mueller, T. G. – Thomas, G. W. – Barnhisel, R. I. – Wells, K. L. – Shearer, S. A. (2000): Soil electrical conductivity variability. In: Robert PC, et al. (eds): Proc 5th international conference on precision agriculture. Madison, WI: ASA Misc. Publ., ASA, CSSA, and SSSA.
- Hemmat, A. – Eskandari, I. (2004): Conservation tillage practices for winter wheat – fallow farming in the temperate continental climate of northwestern Iran. *Field Crop Res.* **89**, 123–133.
- Kang, S. – Zhang, L. – Liang, Y. – Dawes, W. (2003): Simulation of winter wheat yield and water use efficiency in the Loess Plateau of China using WAVES. *Agricultural Systems.* Volume **78**, (3) 355–367.
- Késmárki I. – Halupa L. – Palkovits G. (1993): Erdőtársulás és szántóföldi növénytermesztés kapcsolata a vízzel. (Connection of forest coenosis and field crop production with water) Symposium „Wasser im Pannonischem Raum”, Sopron. 197–203.
- Kravchenko, A. N. – Bullock, D. G. (2000): Correlation of corn and soybean gain yield with topography and soil properties. *Agron J.* **92**, 75–83.
- Lampurlanes, J. – Angus, P. – Cantero-Martinez, C. (2002): Tillage effects on water storage during fallow, and on barley root growth and yield in two contrasting soils of the semi-arid Segarra region in Spain. *Soil Tillage Res.* **65**, 207–220.
- Lawes, R. A. – Oliver, Y. M. – Robertson, M. J. (2009): Integrating the effects of climate and plant available soil water holding capacity on wheat yield. *Field Crops Research.* Volume **113**, (3) 297–305.
- Milne, B. T. (1991): Heterogeneity as a multiscale characteristic of landscapes. In: Kolasa J, Pickett STA, editors. Ecological heterogeneity Ecological studies. Volume **86**, New York, NY: Springer-Verlag, 69–84.
- Nagy, V. – Štekaurová, V. – Neményi M. – Milics G. – Koltai G. (2007): The role of soil moisture regime in sustainable agriculture in both sides of river Danube in 2002 and 2003. *Cereal Research Communications.* **35**, 821–824.
- Nagy, V. – Štekaurová, V. – Milics G. – Lichner, L. – Neményi M. (2008): Harmonisation of different measuring methods of soil moisture used in Žitný Ostrov (SK) and Szigetköz (HU). *Cereal Research Communications,* **36**, 1475–1478.

- Nyiri L. (szerk.) (1993): Földműveléstan. (Tillage science) Mezőgazda Kiadó, Budapest.
- Palkovits G. – Schummel P. (1992): Növénytermesztési kutatási eredmények a Szigetközben. (Results of crop production research in Szigetköz) Acta Óvariensis. Mosonmagyaróvár, **34**, 75–87.
- Papp Z. – Fenyvesi L. (2007): Új távérzékelési módszer a mezőgazdaságban és a környezetgazdálkodásban. Mezőgazdasági technika. **1**, 26–28.
- Pepó P. (2009): Eltérő évjáráttípusok és agrotechnikai tényezők interaktív hatása az őszi búza (*Triticum aestivum* L.) termésére. (Interactive effects of various years and agrotechnical factors on winter wheat (*Triticum aestivum* L.) yield) Növénytermelés. **58**, (2) 107–122.
- Rajkai K. (1993): A talajok vízgazdálkodási tulajdonságainak vizsgálati módszerei. (Different methods for soil moisture regime research) In *Búzás I. (ed): Talaj- és agrokémiai vizsgálati módszerkönyv 1. A talaj fizikai, vízgazdálkodási és ásványtani vizsgálata*. INDA 4321 Kiadó, Budapest. 115–160.
- Rajkai K. – Rydén, B. E. (1992): Measuring areal soil moisture distribution with TDR method, Geoderma, Volume **52**, 73–85.
- Sharma, B. D. – Kar, S. – Jalota, S. K. (1993): Effect of irrigation and nitrogen on root growth and prediction of soil-water profiles in wheat (*Triricum aestivum*). Indian J. Agric. Sci. **63**, 8–13.
- Sharma, B. D. – Kar, S. – Sarkar, S. (1997): Calibration of a water uptake simulation model under varying soil moisture regime and nitrogen level for wheat crop. Agricultural and Forest Meteorology. Volume **83**, (1–2) 135–146.
- Shen, S. H. – Gao, W. Y. – Li, B. B. (1999): Water consumption and its impact on yield of winter wheat in Xifeng. Journal of Nanjing Institute of Meteorology. **22**, (1) 88–94.
- Stefanovits P. (1975): Talajtan. (Soil science) Mezőgazdasági Kiadó, Budapest.
- Štekauerová, V. – Nagy, V. – Kotorová, D. (2006): Soil water regime of agricultural field and forest ecosystems. In: Biologia. Volume **61**, Suppl. 19.
- Šátor, J. – Štekauerová, V. – Nagy, V. – Rodný, M. – Šurda, P. – Milics, G. – Neményi, M. (2009): Agricultural ecosystems protection by the soil water regime stabilization. 5th Crop Production Science Day. Akadémiai Kiadó, Keszthely, 209–212.
- Tao, S. (1998): Factor score mapping of soil trace element contents for the Shenzhen area. Water Air Soil Pollut. **102**, 415–25.
- Williams, B. G. – Hoey, D. (1987): The use of electromagnetic induction to detect the spatial variability of salt and clay contents of soils. Aust J Soil Res. **25**, 21–7.

Address of the authors – A szerzők levélcíme:

BALLA István
SZIE-MKK
Institute of Crop Production
H-2100 Gödöllő, Páter Károly utca 1.
E-mail: Balla.Istvan@mkk.szie.hu