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Gödöllő

**Nitrogen fertilization analysis on small plot winter
wheat experiments and soil moisture detection in
precision farming**

Thesis of doctoral dissertation (PhD)

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Table of contents

1. Background and objectives	4
2. Materials and methods	6
2.1. Materials and methods used for the small plot experiments	6
2.1.1. Agro-ecological characteristics of the experimental area	6
2.1.2. Setting and sustaining the experimental conditions and the applied treatments	7
2.1.3. Statistical data analysis.....	8
2.2. Materials and methods used for the precision experiments.....	8
2.2.1. Agro-ecological characteristics of the experimental area and the times of sampling	8
2.2.2. Location and distribution of the sampling points.....	10
2.2.3. Test methods	12
2.2.4. Data management and statistical analysis	13
3. Results	14
3.1. Results of small plot experiments.....	14
3.2. Results of precision research (2009, 2011, 2012)	17
3.3. New scientific results.....	22
4. Conclusions and Recommendations.....	23
4.1. The lessons learned from small-plot trial	23
4.2 The lessons learned from the soil moisture assessment	24
5. Scientific publications	27

1. Background and objectives

Human population approaches 7.4 billion today. According to the data of the German Foundation for World Population (DSW - Deutsche Stiftung Weltbevölkerung), the world population increased with about 83 million only in 2015. The growing population requires efficiency in food production, increase in volume and improvement in the quality of the produced food. One of the solutions or mitigations of the problem can be the precision farming or site-specific crop management aimed to improve efficiency of the production by keeping the environmental aspects in mind and using the most advanced technology.

Today, in addition to precision farming important role is played by small-plot comparison, cultivation, plant protection and plant nutrition in experiments. As a result, choice of varieties and the entire production technology can be adapted to the habitat conditions. These field trials rarely identifies a link between the physical environment and the production so they are site specific which means that results of one field can rarely apply to other site conditions. An important function of the different areas of agronomy, which research the mechanism that make a link among water, soil and plant is the extension of the field trial results (*Berzsenyi, 2009*)

Two topics were examined in the doctoral dissertation:

The first research of the Institute of Crop Production of the Faculty of Agricultural and Environmental Sciences at Szent István University was comparative tests of nitrogen fertilization analysis on small plot winter wheat experiments in which production was examined with a view to the different volume of used N fertilisation in the period of four years. Since one of the basic pillars of precision farming is the maximal use of yield potential, the extensive testing of production under different agro-ecological conditions is needed.

In the second part of my thesis research carried out together with the Agriculture and Food Science Department of Biosystems and Food Technology Institute at the Széchenyi István University (SZE-MÉK BRMI) is presented where we attempted to implement a high sample density, site-specific soil moisture measurement. The two research methods of measuring soil moisture and soil electrical conductivity measurements were compared statistically. Our aim was to examine whether there is a correlation between

soil moisture conditions and soil the specific electric conductivity. If the soil electrical conductivity mapping is suitable to determine the soil moisture conditions soil moisture measurements become faster, simpler, more detailed, more cost-effective and more precise in space.

The aims of our research:

1. Examining the effect of increased N doses on the winter wheat yield production based on the comparative small plot variety trials results.
2. Examining that the divided use of N fertilizer results in yield increase, enhance yield safety, moderate year impact compared to the single fertilizer done by top dressing.
3. Examining whether high dose of N fertilization done by top-dressing always results in yield growth and increases yield stability compared to lower doses of single or divided fertilization.
4. Comparison of the effects of different vintages on certain varieties' yield with a view to the applied N doses.
5. Identifying proposals on those crop varieties that can be grown with the highest yield security based on the certain varieties' yield in the different vintages.
6. The objective was to prove that the measurement of the soil electrical conductivity provides with data appropriate in number and distribution for precision agricultural fields.
7. The other aim of the research was to develop different "management zones" in heterogeneous soil based on specific electric conductivity grounded on high resolution and the separated treatment of them in the future.
8. Soil specific electrical conductivity is measured with the purpose to see if it is suitable for mapping and to estimate the state of the soil moisture indirectly.

2. Materials and methods

2.1. Materials and methods used for the small plot experiments

2.1.1. Agro-ecological characteristics of the experimental area

Location: An experimental agricultural plot of the Institute of Crop Production of the Faculty of Agricultural and Environmental Sciences at Szent István University Faculty, approximately 5 ha in size. The location of the small plot experiment is in the outer area of the municipality of Hatvan-Nagygyombos, more precisely in the triangle enclosed by the M3 motorway, National road no 21. and the Hatvan-Salgótarján railway line (**Figure 1**). The owner of the field is a private farmer.

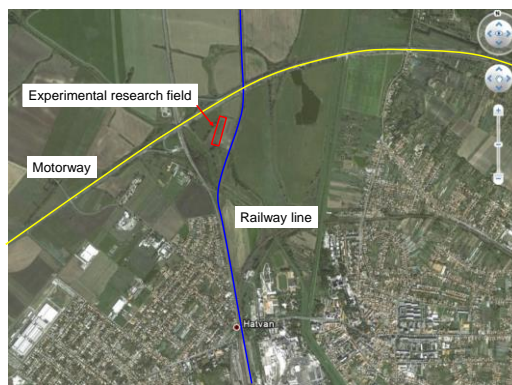


Figure 1 Location of the Nagygyombos experimental area (Wallpaper: GoogleEarth)

The annual average temperature of the area is 10.3 °C and annual precipitation varies between 560-580 mm.

Weather in the years examined: In the first year of the experiment (2008), in the period from August to July, the region's overall precipitation was 695.7 mm which is 120-140 mm more than the long term average. Overall precipitation in the 2nd year of the experiment (480.3 mm, in 2009) was 200 mm less in comparison to the previous year. 2010 was an extremely rainy year in Hungary with respect to the long term average, as the total precipitation (799.2 mm) was well above it. The large quantities of rainfall resulted in inland water over a large part of the experimental area, having a depressive effect on its flora. In 2011, total precipitation was 665.8 mm, which is above the average, just as it was during the preceding year.

Soil: The experimental area's soil is chernozem-brown forest soil, its most important average soil test result are shown below (5 August 2007):

organic matter content:	2.65%
CaCO ₃ :	1.86%
pH (KCl):	7.30
KA:	45
P ₂ O ₅ (mg kg ⁻¹):	463 (AL-soluble)
K ₂ O (mg kg ⁻¹):	293 (AL-soluble)
N (mg kg ⁻¹):	0.9 (total mineral cont.)

From the measurement results of the soil samples, it is well seen that the area has a satisfactory supply of phosphorus and potassium, therefore basic fertilisation only plays a sustaining role. As for feeding the flora, nitrogen is of exceptional significance, as this is the only macro element in limited supply for the plants.

2.1.2. Setting and sustaining the experimental conditions and the applied treatments

Layout: The comparative small plot winter wheat we have arranged is a split-plot experiment. In this case, the cultivar represented the main parcel factor and the various fertiliser treatments represented the sub-parcel factors. In our experiment the effects of 6 nitrogen doses (one control and 5 treatments) were examined for 5 cultivars in 4 repetitions.

Cultivars: The varieties set in the experiment were selected with the aim of picking those with high yields as well as high protein and gluten contents as these react easier to the doses of active ingredients delivered. Four of the five selected cultivars were Martonvásár wheat (Mv Csárdás, Mv Magdaléna, Mv Suba, Mv Toborzó) and an older, but well-performing cultivar which had received state recognition back in 1987, the Alföld-90 (later known as Alföld).

Plant nutrition: As a basic fertiliser, one unit (300 kg ha⁻¹) of complex (N:P:K=15:15:15) fertiliser was delivered using a splash plate broadcast spreader. The various single N doses (0, 40, 80, 120 kg ha⁻¹) were delivered in spring as top-dressing, at the time of tillering. In the case of double and triple N doses (split top-dressing: 80+40, 80+40+30 kg ha⁻¹), the first application was delivered at the time of tillering, the second at stem elongation, and the third nitrogen dose was delivered upon the appearance of the flag leaves. Top-dressing was performed manually in each case, given the small size of the plots, after doses had been precisely measured out.

Tillage: The area managed according to the sequencing requirements of crop rotation was selected so that the preceding crop should be the same in each year examined and in our case it was dried beans. In the examined period, rotary ploughing was applied at a depth of 28-32 cm in each case after stubble-ploughing, which was then flattened out with a roller. Preparation of the seed beds was carried out prior to sowing in each case, with the help of a spring-hoe combinator.

Sowing: Sowing was performed every year with the institute's 8 row, sliding coulter Wintersteiger Plotman plot seeder (Wintersteiger GmbH., Ried, Austria).

Cultivation routes: The cultivation routes across the tillering winter wheat field sowed using the split-plot system were created during the spring with the help of a rotary tiller.

Plant protection: The plant protection treatments (weed control, application of fungicides, etc.) was carried out in each case with a knapsack-type portable sprayer, therefore no wider access routes than created for sowing were necessary.

Harvesting: Harvesting was performed using the Wintersteiger Nurserymaster (Wintersteiger GmbH., Ried, Austria) plot harvester owned by the Institute of Crop Production.

2.1.3. Statistical data analysis

Statistical analysis (two variable analysis of variance /ANOVA/) of yield was carried out with the help of the GenStat programme. Variance analysis only shows whether a significant difference exists among the results evaluated, but it doesn't indicate the groups among which the difference emerged. In order to identify this data, a Duncan multiple range post hoc test was carried out. The objective here was the creation of homogeneous groups.

2.2. Materials and methods used for the precision experiments

2.2.1. Agro-ecological characteristics of the experimental area and the times of sampling

Location: The research area is found in the outer area of Mosonmagyaróvár, close to national road no 150. The plot is the experimental area of the Institute of Biosystems and Food Engineering of the Faculty of Agricultural

and Food Sciences of Széchenyi István University (**Figure 2**), a plot of 23.52 hectares which has been in precision cultivation since 2001; its MEPAR code being K2XEW-8-08.



Figure 2 Location of the experimental area (Wallpaper: GoogleEarth)

Soil: The area is an alluvial plain under intensive agricultural cultivation. The plot cultivated with the precision method is heterogeneous, meaning one soil profile description will not characterise it. The reason for this particular heterogeneity is the ancient riverbed running underneath the area. The bulk density of the upper 20 cm of the soil varies between 1.1-1.4 g/cm³ according to the plot's pattern (Nagy, 2004).

The times of sampling:

1. 28 July 2009: Sampling was performed after the harvest of the winter wheat, on unploughed stubble.
In 2010, it rained continuously at the planned time of the measurements, therefore no measurements were taken in this year.
2. 13 April 2011: Prior to preparing the seed-beds, the area's soil moisture and specific electric conductivity were measured, after which the seed-bed for corn was prepared.
3. 14 November 2012: The tests were conducted after the harvest of the soybean, on crushed, but not ploughed stubble.

Precipitation data for the 30 days preceding the measurement: The values of the precipitation quantities are based on the data registered by the Meteorological Station of the Faculty of Agricultural and Food Sciences of the University of West Hungary. In the year of 2009, the months of June and July were extremely wet in comparison to the long term average (1981-

2010). In June, a total of 135 mm rain fell, which is double the long term average (66.8 mm). In 2011 – a year much more dry than the examined year 2009 – a total of 45.7 mm rain fell in the 30 days preceding the tests, a large proportion of which (28.3 mm) fell in the month of March. In the third year of the experiment (2012), the precipitation of the 30 days before measurement provided a total of 82.5 mm of water for the soil.

2.2.2. Location and distribution of the sampling points

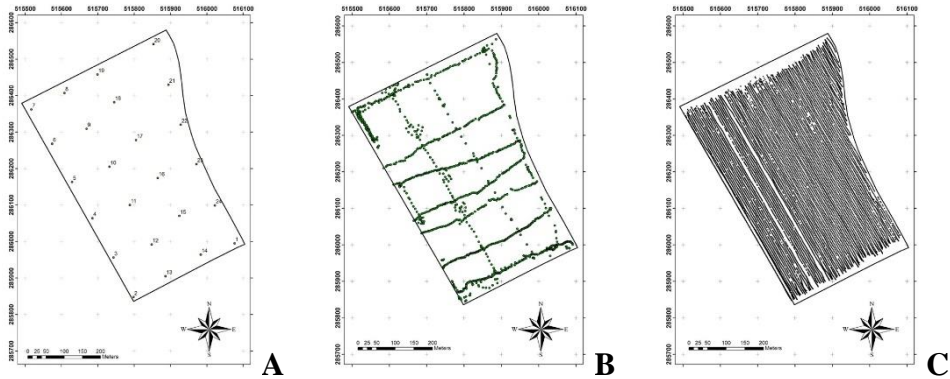


Figure 3 Locations of the sampling points in 2009 (gravimetric soil samples, TDR-300 and Veris 3100)

Figure 3 shows the locations of the measuring points for 2009 in the agricultural plot examined. Picture **A** shows the sampling locations for the soil samples taken for the gravimetric soil moisture tests (24 pcs). Picture **B** shows the locations of the soil moisture measurements carried out with the TDR-300 measuring instrument. In the course of the measurements, soil moisture was measured in 1364 points of the area. Picture **C** shows the sampling locations of the specific electric conductivity measurements performed with the Veris 3100 device (13531 pcs). For gravimetric sampling, the measuring points were located in order to obtain measurement data from every point of the plot. For the test with the TDR-300 instrument, the plot was measured both longitudinally and transversally, but the distribution of the sampling points did not turn out to be even, as the lines were picked visually. The sampling most homogeneous distribution was provided by the measurement performed with the Veris 3100 device, due to the densely packed rows and the high frequency of measurements (1 every second). To obtain a full mapping of the plot, the possibly highest quantity of data is required, as an authentic map can only be drawn using a large number of evenly distributed data.

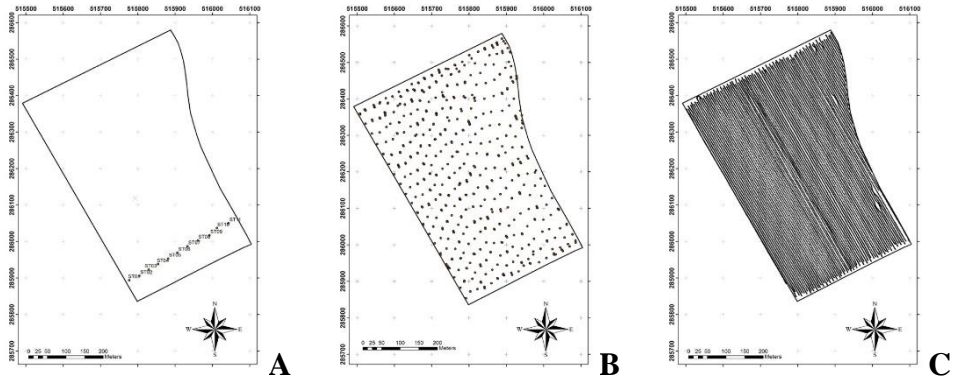


Figure 4 Locations of the sampling points in 2011 (gravimetric soil samples, TDR-300 and Veris 3100)

Figure 4 shows the sampling points for the year 2011. Undisturbed soil samples were only taken from a single row this year (11 pcs), as shown on *Figure A*. For the measurements performed with the TDR-300 in 2011, we tried to implement a homogeneous distribution of sampling points (654 pcs), whose results are shown in picture *B*. Picture *C* shows the measurement points if the year 2011 with the Veris device (15249 pcs) showing no difference from the year 2009.

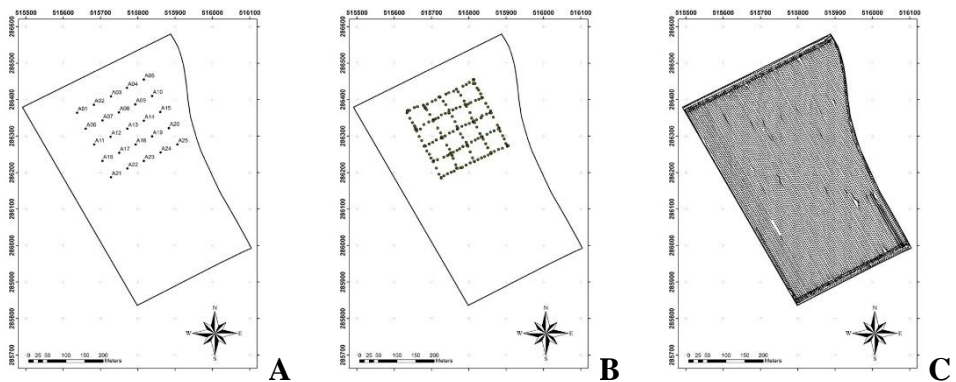


Figure 5 Locations of the sampling points in 2012 (gravimetric soil samples, TDR-300 and Veris 3100)

25 undisturbed soil samples were taken in the 2012 measurements. The locations of the sampling points are shown in picture *A* of *Figure 5*. It can be seen from the picture that the location of the samples were in squares of 5 x 5. Part *B* of the figure shows the sampling points (255 pcs) of the TDR-300 soil moisture measuring device, following a gravimetric measuring strategy. For the measurements conducted with the Veris 3100 device we

obtained a total of 10973 sampling points that showed the most homogeneous distribution in this year, too (picture C).

2.2.3. Test methods

Gravimetric soil moisture-measurement: Undisturbed soil sampling had been performed in all three years of the experiment. Taking and preserving the undisturbed samples until testing was done using Kopeczky cylinders (100 cm³). The weight of the samples was measured before placing them in drying chambers and drying them to mass constancy at 105 °C. Due to the small number of sampling points, no map was prepared from the gravimetric soil moisture data, but the data were used for controlling the results of the field soil moisture tests instead.

Volumetric determination of soil moisture: For preparing the soil moisture map, a Spectrum TDR-300 (**Figure 6**) type soil moisture meter was used. The device – with the connected GPS receiver – also stores the coordinates of the location of the measurement besides the moisture content data. The capacity of the built-in memory is 1350 measurements with GPS coordinates and 3250 measurements without GPS coordinates.



Figure 6 Construction and application of the Spectrum TDR-300 soil moisture measuring device

Measurement of the soil's specific electric conductivity (EC_a): Simultaneously to the soil moisture measurement, specific electric conductivity of the soil was measured with the help of the Veris 3100 device (**Figure 7**) by passing it all over the plot. The most important elements of the Veris 3100 measuring device are the 6 discs, each measuring $\varnothing 430$ mm in diameter, which are electrically isolated from all other parts. Pulling the device evenly, the pair of electrodes sunken in the soil enters a current of known voltage into the soil, and the other pair of rolling electrodes measures

the voltage drop continuously. The two electrodes in the middle detect the electric conductivity at a depth of 30 cm, while the two at the sides read that of the 0-90 cm soil layer. The present study only used the data obtained for the 0-30 cm soil layer. Veris 3100 stores the measured data every second. The coordinates of the measurement have also been taken. At the end of the measurement the data can be saved on computer.

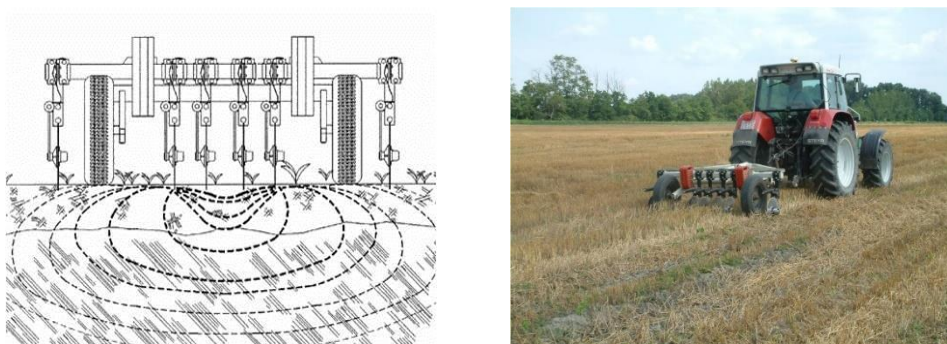


Figure 7 The principle of operation and the use of Veris 3100

Based on data obtained from literature, in case of low salt (not saline) soils, conductivity allows to draw conclusions about the moisture content of the soil, its fractional composition, i.e. the relative volumes of sand, humus and clay it contains.

2.2.4. Data management and statistical analysis

The GPS system we used attributed WGS84 (World Geodetic System) geographical coordinates to the moisture and conductivity data, which were converted with the EHT² programme to coordinates of the EOV (Unified National Projection System) used in civic mapping in Hungary.

The saved data were read in with the ArcGIS ArcMap 10.1 programme, and the soil moisture and electric conductivity map of the area was prepared with the help of the IDW (Inverse Distance Weighting) interpolation procedure (5 m).

Excessive figures from among the large volume of data were outsourced using the ArcMap/ArcView software. Upon examination of the histogram of the values obtained, the key descriptive statistical data appear as statistical analysis is activated. The full database does not follow a standard deviation and also contains zero and negative values as well. Removal of the excessive data was performed using the normal QQPlot geostatistical analyser module, using the interquartile range (IQR) distance.

3. Results

3.1. Results of small plot experiments

Table 1 Results of the variance analysis of the four years (2008-2011)

Source of Variance	Degree of freedom	F-values			
		2008	2009	2010	2011
Repetition	3				
Varieties (A)	4	11,11***	112,3***	60,1***	78,03***
Fault (A)	12				
Nutrition (B)	5	84,6***	150,55***	63,93***	130,77***
A x B	20	1,48 ^{ns}	2,12*	1,16 ^{ns}	1,19 ^{ns}
Fault (B)	75				
All	119				

Table 1 shows the results of two-factor analysis of variance that was performed in each year of the study. From the results obtained it is obvious that each year there was a significant difference between the cultivars already on 0.1% significance level. The effect of - nutrient treatment (0.1%) was also significant in all years of our study. In case of the cultivar x nutrient interactions there was a significant difference only in 2009 on 5% level.

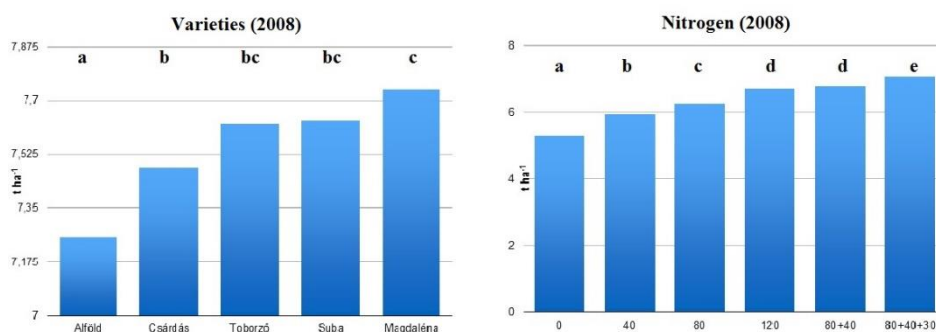


Figure 8 Comparison of varieties and applied N doses, Duncan-test (2008)

2008: After having done the Duncan-test (**Figure 8**) significant differences were observed in three types (Alföld, Csárdás, Magdaléna) however the yields of Suba and Toborzó varieties didn't differ significantly either from each other or from the yields of Csárdás and Magdaléna. The comparison of the different N data showed a significant difference in all level of N. The only exceptions were seen in the case of the single 120 kg N application and in the case of the divided N doses (80+40 kg) where there was no significant difference in yields.

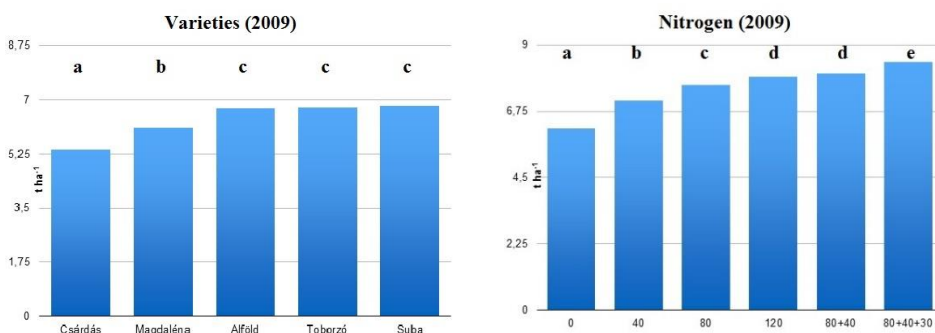


Figure 9 Comparison of varieties and applied N doses, Duncan-test (2009)

2009: According to the Duncan-test (**Figure 9**) there was a significant difference in yields between the Csárdás and Magdaléna wheats and in the other 3 varieties (Alföld, Toborzó, Suba). The Duncan-test didn't show significant difference among the yields of Alföld, Toborzó and Suba types. Differences in the doses of N were compared by the Duncan test as well. The result of the test falls in with the previous year's result as significant differences were measured in the applied doses of fertilizer. In 2009 the exception was again the divided and the single applications of the 120 kg N as there was no significant difference between the yields.

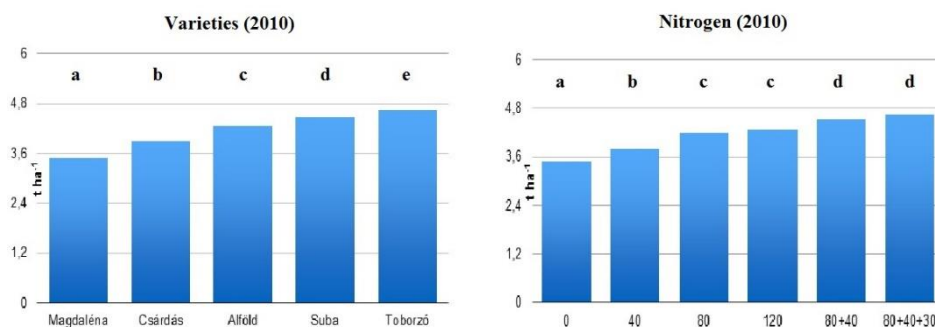


Figure 10 Comparison of varieties and applied N doses, Duncan-test (2010)

2010: Duncan-test (**Figure 10**) showed that there were significant differences among all types of wheats. Significant difference was shown among the 0, 40, 80, 120kg N, the 80+40kg N doses and the 80+40+30kg N doses. However, there were no significant differences among the 80 and 120 kg, and 80+40 kg and 80+40+30 kg N-doses.

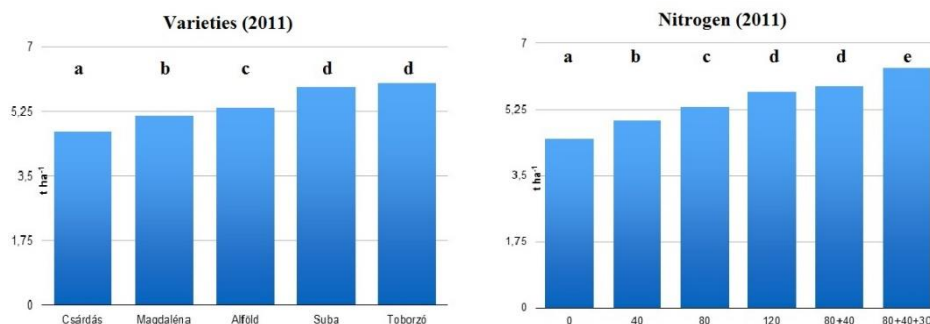


Figure 11: Comparison of varieties and applied N doses, Duncan-test (2011)

2011: Duncan-test, aimed to compare the different types, identified significant differences among the Csárdás, Magdaléna and Alföld types and between the mentioned types and the pair of Suba and Toborzó varieties. Significant difference was not shown between Suba and Toborzó types. The Duncan-test for N treatment showed the same result as it was in the first two years of experiment (2008-2009). The test didn't show significant difference between the use of single and divided use of the 120kg N however, apart from this result there was significant difference in all other nutrition levels.

2008-2011:The follow-up of the the avarage yield per year was carried out by the Duncan-test (**Figure 12**) as well. In all four years of the test period the yearly yield differed significantly (**Table 2**) from the other three years' results. As a result of the experiment we came to the conclusion that vintage has the greatest impact on the winter wheat yield that is followed by N fertilisation and the variety affect. The impact of the N fertilisation was two times as important as the variety impact however the interaction of the vintage and N fertilisation and vintage and variety were also significant.

Source of Variance	Degree of freedom	Calculated F -volume
Repetition	3	
Variety (A)	4	125,26***
Fault (A)	12	
Nutrition (B)	5	357,18***
A x B	20	1,58 ^{ns}
Fault (B)	75	
Year (C)	3	2998,85***
A x C	12	33,56***
B x C	15	7,5***
A x B x C	60	1,43*
Fault	270	
All	479	

Table 2 Results of combined variance analysis

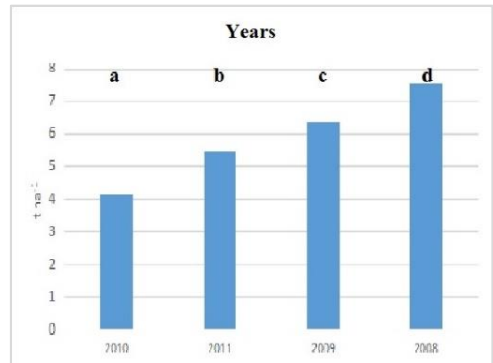


Figure 12 Comparison of years, Duncan-test (2008-2011)

3.2. Results of precision research (2009, 2011, 2012)

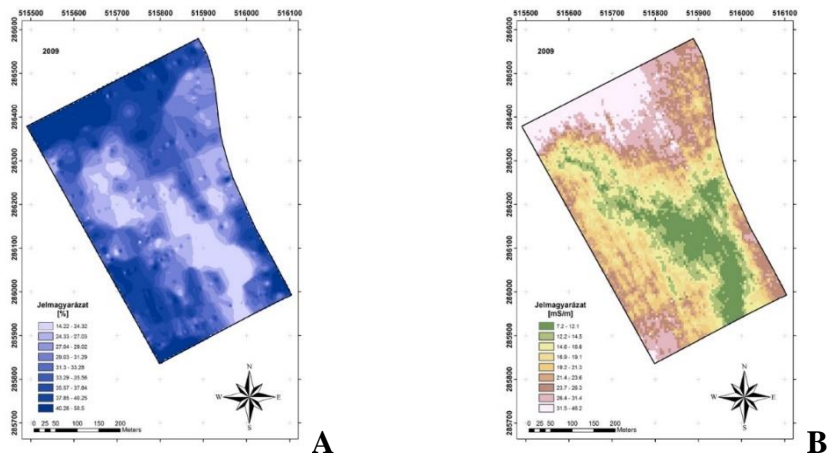


Figure 13 The soil moisture and specific electric conductivity maps (2009)

In order to prepare maps we used those more representative measurement types (TDR-300, Veris, 3100), that are having large number of samples as high sampling density and equipartition are essential elements for geostatistical mapping. We observed similar patterns (**Figure 13, 15, 17**) among the maps in the experimented period and we aimed to verify it statistically.

2009: After having taken away the excessively high data we got 1195 pieces of soil moisture (TDR) and 13446 pieces of specific electric conductivity data (Veris) for further research.

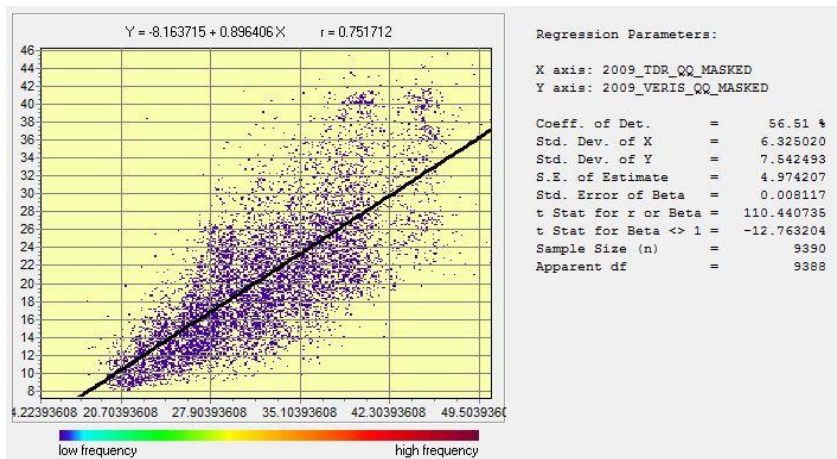


Figure 14 Correlation between soil moisture (TDR) and specific electric conductivity (EC) (2009)

The data of the TDR-300 (**A**) and Veris 3100 (**B**) mapping were compared (**Figure 14**) by Regression analysis with the help of the ArcGIS ArcMap program in which in the case of 9390 pairs of samples for the value 'r' 0,75 were identified and the the determination coefficient rate became 56.51% which assumes moderate correlation. As the program was not always able to couple the specific electric conductivity data with moisture data (fewer samples) it counted on the interpolated humidity data. In order to verify the correlation measured in 2009 we used the existing gravimetric soil moisture measurements' data and that was used to control the 300-TDR moisture measurement metrics. Volumetric soil moisture data measured by gravimetric and TDR-300 were compared by Regression analysis. The outcome showed that the correlation in 24 points is tight as the result was $R^2=0.79$.

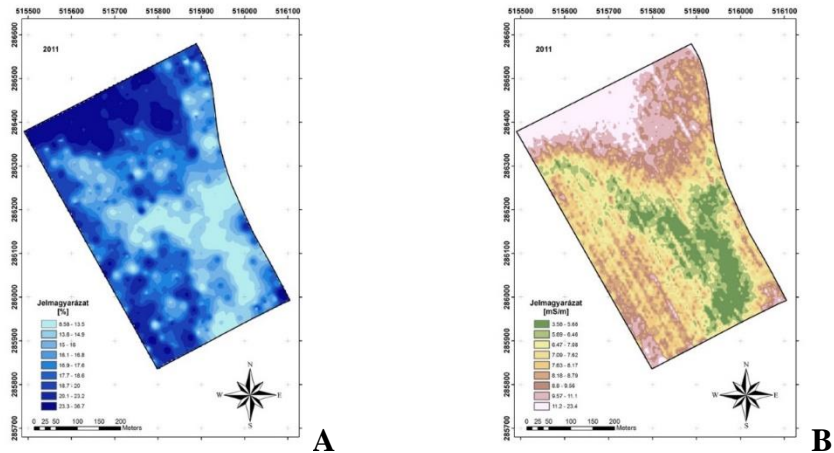


Figure 15 The soil moisture and specific electric conductivity maps (2011)

2011: In order to determine the soil gravimetric moisture we took undisturbed soil samples from eleven places. In spite of this soil moisture were measured in 649 points by TDR-300 and Veris-3100 device mapped the soil specific electric conductivity in 15249 point. The TDR (**A**) and Veris (**B**) maps showed similar patterns (**Figure 15**) though in order to justify our assumption further statistical analysis were performed.

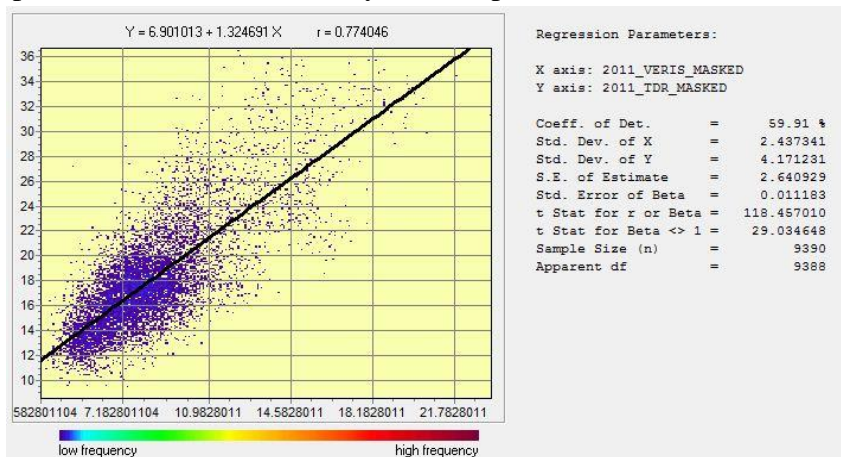


Figure 16 Correlation between soil moisture (TDR) and specific electric conductivity (EC) (2011)

Based on the interpolated values and using 9390 pairs of data the ArcGIS program compared soil moisture and conductivity data (**Figure 16**). The result of the determination coefficient was 59,91% so the correlation was considered moderate again.

The comparison of gravimetric soil samples' results (11 pieces) and TDR-300 moisture data were carried out by regression analysis and TDR data were compared to conductivity (Veris) data. The research resulted in $R^2=0,8039^*$ in the first case while the latter has resulted in $R^2 = 0.8514^*$ value, so the relationship was considered tight again.

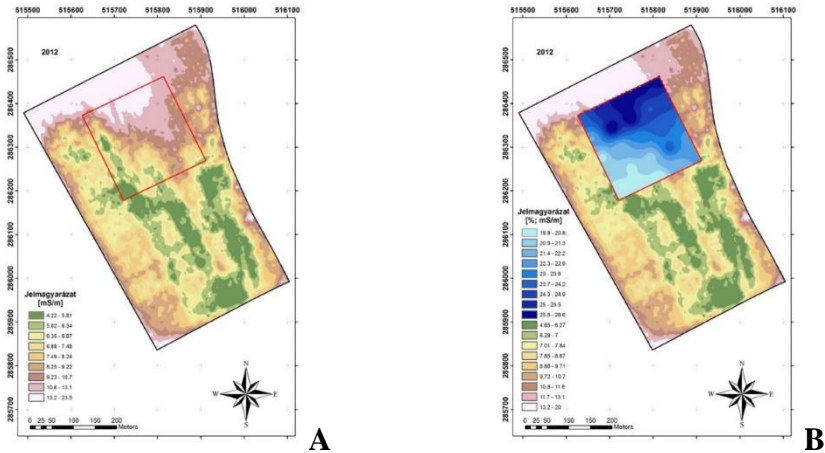


Figure 17 The soil moisture and specific electric conductivity maps (2012)

2012: In the last year of the research the size of the sampling area was reduced. We received 25 gravimetric data, 255 volumetric soil data and 10973 conductivity data. Maps (**Figure 17**) made on the basis of the moisture and the specific electric conductivity showed similar pattern for the 3rd time and we made statistical evaluation as well to confirm the correlation. As a result of the reduced size of the sampling area the numbers of the data pair in the ArcView program were 1807. As a result of the test (**Figure 18**) the correlation between the two set of data considered to be strong as the received correlation coefficient is 79%.

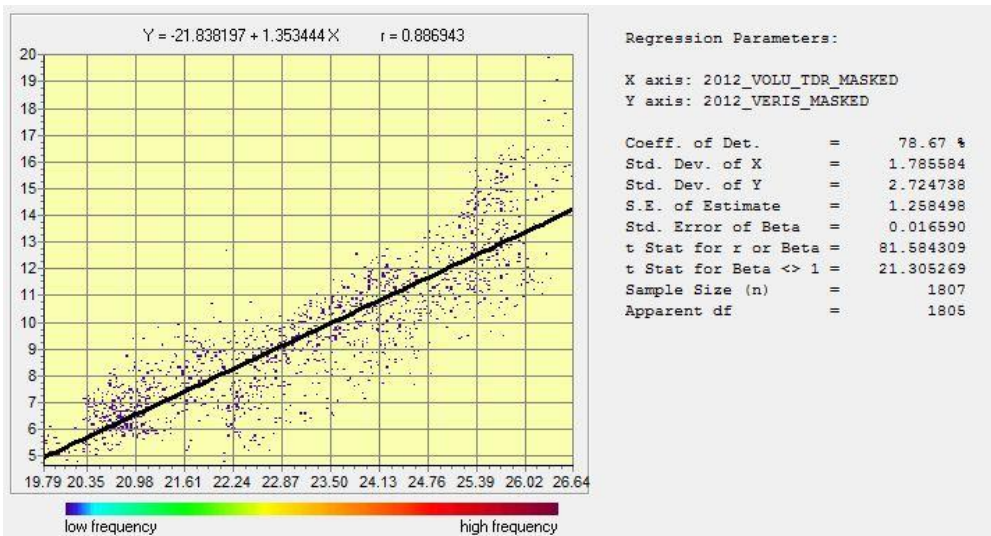


Figure 18 Correlation between soil moisture (TDR) and specific electric conductivity (EC) (2012)

In order to prove the correlation, regression analysis was performed in which the measured 25 gravimetric data was compared with the measured data of the TDR-300. The test proved a tight correlation among the set of data as the result was $R^2=0.86$. Regression analysis was used to compare the specific electrical conductivity of soil with the measured values of volumetric soil moisture. Tight correlation between the two set of data was proved as the value of R^2 was 0.81.

As a result of the research it was proved in all three years that the tiring, time-consuming and pricy (undisturbed sample analysis) soil moisture measurement procedures can be indirectly substituted by the specific electric conductivity soil determination. As a result of the methodology, the detection of conductivity results in data, appropriate in number and distribution that are suitable for precision data collections and with the use of it agricultural fields can be mapped in great details. According to the specific electrical conductivity map, the spatial heterogeneity of soil moisture can be considerably mapped which can serve a basis to form the different management zones in the future.

3.3. New scientific results

1. In the case of small plot winter wheat trials it was proved in the tested field in three years out of four that there was no significant difference in yields by applying a 120 kg single N fertilization at the beginning of tillering and the divided (80+40 kg N) fertilization applying it at the beginning of tillering and at the time of stem elongation as top dressing.
2. In wet years, the divided N fertilization increased the crop safety in the examined agro-ecological environment as the amount of N leaching from the root zone was less and more of the applied active substance was utilized.
3. On chernozem-brown forest soil maximum caryopsis was reached in all four years of experiment by applying the highest dose of N (150 kg/ha) with the method of divided top dressing in the case of all varieties.
4. A map can be generated from the measured specific soil electronic conductivity's set of data which can characterize the spatial and temporal diversity of the shallow layer of soil. The method can be used to separate the areas owning different soil conditions in the field and also to develop management zones.
5. We came to the conclusion that the inhomogeneity of a specific area influenced the normal distribution of the measured data. In the examined cases normal distribution was not reached even after that the excessively high data had been taken away. Results of statistical analysis, however, do not limit the measurement's accuracy.
6. According to the comparative methodological analysis, specific electric conductivity measurements done by Veris 3100 device are suitable for mapping rapidly the soil moisture status.

4. Conclusions and Recommendations

4.1. The lessons learned from small-plot trial

Based on comparison of the examined four years of small plot winter wheat varieties and the N fertilisation trial we came to the conclusion that increased use of N doses resulted in yield increase in the case of all varieties.

Three years (2008, 2009 and 2011) of the experiment show significant differences among the yields as a result of the applied different level of N. The yield of the tested winter wheat varieties increased as a result of the increased doses of N fertilisation. Exceptions are the utilization of the single and divided uses of the 120kg N, as there was no significant difference between the two N levels (method of application) in the mentioned three years. It means that the division of the top dressing's dose increased the yields but it can't be verified statistically.

Examining the effect of the N top dressing there is a positive outcome of the divided application of fertilizer on yields in the extremely wet year of 2010. In this cycle, the applied divided N doses (80+40 kg N, 80+40+30 kg N) resulted in statistically verified increased yields compared to the single application of top dressing though there was no significant difference between the two divided N doses. There was no statistically proved significant difference between the yields fertilized by single fertilization of 80kg N and 120kg N which can be explained by the nutrition leaching caused by the extreme rainfalls.

The nutrient responses of the varieties show that the varieties of Alföld, Mv Csárdás and Mv Magdaléna had lower yields in the examined three years (2009, 2010 és 2011) than the varieties of Mv Suba and Mv Toborzo. From that result we concluded that in the terms of production site Suba and Toborzo utilized the applied nutrients better so their crop safety is prominent in the region. From the mentioned two varieties of Martonvasar the yield of Toborzo outperformed the Suba's yield in two years (2010 and 2011) so Toborzo can be more safely recommended for the region. The perfect nutrient utilisation of this variety is shown that it gave the highest yield in the extremely rainy year as well. Among the tested varieties the Alföld 90, the oldest recognized variety reached the third place in terms of

yield amount in every three year so among the younger, more intense varieties – in relation to the specific region – it is still measured to be able to provide a balanced yield and considered as a reliable variety. It is clear from the comparison of the varieties with the view to the agro-ecological conditions of the region that the most reliable winter wheat varieties are the Mv Toborzo (Pannon standard – excellent for flour) and the Suba (Pannon Prémium – Prémium quality). According to the outcome, the region is highly recommended for winter wheat cultivation with a view to edible horticulture.

According to the comparative study of the vintages, there were statistically proved differences between the yields every year which proves that the weather has a huge impact on the harvest. Based on the combined analysis of variance test, done in the mentioned four years it is proved that greatest impact on winter wheat yield was the vintages, followed by the effects of N fertilization and the variety. The effect of the N fertilization was double of the varieties' effect though there were significant interactions between the vintages and N fertilisation and between the vintage and the variety.

4.2 The lessons learned from the soil moisture assessment

Based on the comparative study of the soil moisture's (gravimetric and TDR) and specific conductivity's (Veris 3100) measurements, carried out in Mosonmagyaróvár we came to the conclusion that there is a tight correlation among the received set of data examined in the three years as the volume of the regression analysis even in the most moderate case was $R^2=0.7911^*$ (2009). Statistical analysis made by the ArcGIS ArcView programme showed a loose connection in the year of 2009 and 2011 which is likely because of the huge number of samples and the interpolated values of the soil moisture measurements. In the third year of the experiment reduced number of samples and reduced size of sampling area were applied and as a result of a statistical analysis, made by a device, the coefficient of determination was 78.67%.

As a result of the research, it can be stated that it is not feasible to get detailed collection of agricultural land's soil moisture data – used in precision crop production – by using gravimetric soil measurement. In order to display the cartographic, precision farming highly detailed and uniformly distributed sampling is required and that is time consuming, work

demanding, tiring and expensive process due to the undisturbed samples and results are not immediately available.

Field soil moisture determination tests, done by TDR 300 device demonstrated that the device is suitable for determining precisely the humidity state and high sampling score and uniform distribution can be achieved by using the planned sample mapping. In this case soil moisture map can be prepared by using the sample scores and the received data. This method however – in case of high resolution – is still time consuming that is why we examined if the determination of the specific electrical conductivity is applicable to measure the soil moisture indirectly.

Researches of the three years proved that in case of the experimental field in Mosonmagyaróvár determination of the soil specific electrical conductivity is suitable for identifying the variability of soil moisture in the field. Conductivity measurements based on high and uniform distribution of samples are essential to prepare relevant maps in precision farming. Veris 3100 device, used for mapping the soil specific electrical conductivity, is advised to be used to make detailed estimation on the soil moisture indirectly due to its easy use and rapid measurement method.

According to the research carried out it can be stated that the specific electric conductivity filed mapping is suitable to differentiate the heterogeneous soil stains in the production region and to create management zones. These separate management zones can be treated separately in the future with respect to the decision-making.

Further extension of the spatial and temporal measurements are required to determine the link between the soil moisture and the specific electrical conductivity and taking into account the different soil parameters (salt content, clay content, etc) as well.

5. Scientific publications

Scientific publications

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