THESIS OF DOCTORAL (PhD) DISSERTATION

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MOSONMAGYARÓVÁR

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RELATIONSHIP BETWEEN PRECISION CROP PRODUCTION AND SUSTAINABLE AGRICULTURE

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1. INTRODUCTION

The author examines the context of the soil-plant-atmosphere system using the Decision Support System for Agrotechnology Transfer (DSSAT) Ceres-Maize model in the precision site-specific field trials. Field trials were carried out with crop rotation. The experiments were carried out in the experimental field divided into 0.25 ha treatment units (management zones, plots) under different seasonal conditions.

In the course of the research work the author focused on climate change impact on maize yield to the end of the 21st century through maize yield forecasting and sensitivity analysis regarding sustainable crop production. Within the framework outlined above the soil chemical and physical parameters together with the climate database were analyzed. To determine the inaccuracies of predictions the soil physical conditions were measured in the investigated 11 management units in the maize vegetation period. The research activity presented in this thesis establishes the fact that the model predicts differently under varying meteorological conditions depending on clay content and taking into account the soil conditions (penetration resistance, soil texture and soil electrical conductivity). In addition to sustainable crop production, climate databases were adapted into the decision support model while the sensitivity of soil and climate input parameters were determined in this test.

The dissertation highlights the adaptation of precision, site-specific technologies to create an advisory system for an approach to sustainanble agriculture and crop production.

2. MATERIALS AND METHODS

2.1. Study field

The precision, site-specific measurements (2012-2015) were carried out in the 23.9 hectare experimental study field of the Department of Biosystems Engineering, Faculty of Agricultural and Food Sciences, Széchenyi István University in the vicinity of Mosonmagyaróvár, Hungary [N47°54’20.00”; E17°15’10.00”; MEPAR code: K2XEW-3-12]. The field is divided into 66, 0.25 ha treatment units in accordance with the requirements of precision agricultural technology (Fig. 1.). Precision agriculture technologies have been applied on a 15.3 ha agricultural field since 2001. The alluvial plain field cannot be characterized by one typical soil profile: depending on the location, loam, silty loam and sandy loam appear on the field.

2.2. Calibration of the model

The maize yield simulations were carried out for each management unit (66) on the 15.3 hectare area with the model (DSSAT - Ceres-Maize cropping system model version 4.5.1.005). Among the initial parameters, those different agrotechnological elements had to be given that were used every year with the specific production characteristics (reported official field data).

2013 was taken as the base year for the climate impact test, hence the agricultural operations and information technology for that year were used.

2.2.1. Soil parameters

The soil parameter requirements were involved from site-specific soil sampling in 0.30 m depth. The soil sampling was carried out on a 50x50 m grid, dividing the 15.3 ha field into 66 treatment units, in October, 2012.

The model soil data requirements were adapted based on the results of accreditated laboratory (UIS Ungarn Kft., Synlab, National Food Change Safety Office – Soil Conservation Laboratory, Velence). Model soil layers mean 0.3 m depth.

For maize yield simulations of 2010 and 2011 were employing the results of 2009, furthermore soil sampling results' from 2012 were using for additional predictions and climate change impact analysis.

2.2.2. Meteorological parameters

The Meteorological Station of the Faculty of Agricultural and Food Sciences, Széchenyi István University, provides weather data for crop modelling (Mosonmagyaróvár; lat= 47°53'22.44" lon= 17°16'03.53"). It is situated 1.8 km from the research field. This biophysical crop model requires at least four meteorological parameters (daily minimum and maximum temperature, daily rainfall and daily solar radiation). Furthermore, we adapted wind speed (m/s) and relative humidity (%).

2.2.3. Climate databases

The stochastic climate databases for the investigation of the impacts of climate change in our region were downloaded from Ensembles site (project). These climate models (C4I-HadCM3, DMI-ARPEGE, KNMI-ECHAM5, ETZH-HadCM3Q, MPI-ECHAM5, SMHI-BCM) have daily parameters in 25 km^2 resolution at A1B (this scenario assumes balance between the use of fossil fuels and renewable energy sources). The predicted climatic data were spatially investigated used coordinates of the experimental field (lat = 47.905615; lon = 17.252363). The meteorological parameters are supplemented by potential evapotranspiration and lengths of sunshine hours.

2.3. Measurements of soil physical parameters

2.3.1. Soil penetration resistance

The cone (manual) vertical penetrometer (3T System) measurements were carried out on 11 reference points on the basis of EC_a map. The sampling took place in the investigated management units in five replications to a maximum depth of 0.4 m.

2.3.2. Soil apparent electrical conductivity (EC_a) measurement

The soil EC_a was measured by a Veris Soil EC-3100 instrument. In this study only data from the depth of 0–0.3 m was used, as the reference soil samples and *CI* databases were also collected from this depth. The continuous soil EC_a mapping were carried out in 2009, 2011 and 2012.

2.3.3. Soil sampling data for gravimetric measurements

Gravimetric soil sampling measurements were planned across the 11 reference points' within-field – such as soil penetration resistance measurements. The sampling depth was thus 0.3 m. Soil samples were dried to a constant weight (>48 hour) in the oven at a temperature of 105 °C.

The results of cone penetrometer, water content and on-line EC_a measurements were compared with each other and other data originating from investigated management units within field.

2.4. Analysis of plant samples

The maize plant sampling was carried out in the investigated management units on 31 July, 2015. Root length, weight and chemical parameters of random 10 samples were measured in the laboratory.

2.5. Sensitivity analysis

We have investigated the effects of climate scenarios together with soil physical and chemical parameter changes. Fifteen soil physical and chemical parameters (pH_1, pH_{water2}, humus $content_3$, $CaCO_{3\ 4}$, $P_2O_{5\ 5}$, K_2O_6, Ca_7, NO_2-NO_3-N_8, organic $matter_9$, $SO_{4\ 10}$, clay fraction $(\%)_{11}$, bulk $density_{12}$, $homok_{13}$, salt $(\%)_{14}$, silt fraction$(\%)_{15}$) were taken into consideration from 11 designated management zones. The modelling, including input parameter matric, was to run several thousand times (> 2000) in order to have consistent calculated indices. The presented results are based on variance (scattering) and calculated two indices: main effects (first-order) sensitivity index and total effect index.The evaluations were carried out for the two extreme value scenarios: SMHI-BCM and ETZH-HadCM3Q. The climate parameters have been determined with AgMIP (The Agricultural Model Intercomparison and Improvement Project) sensitivity analysis using the following parameters: minimum and maximum temperature, precipitation and carbon dioxide concentration.

3. RESULTS

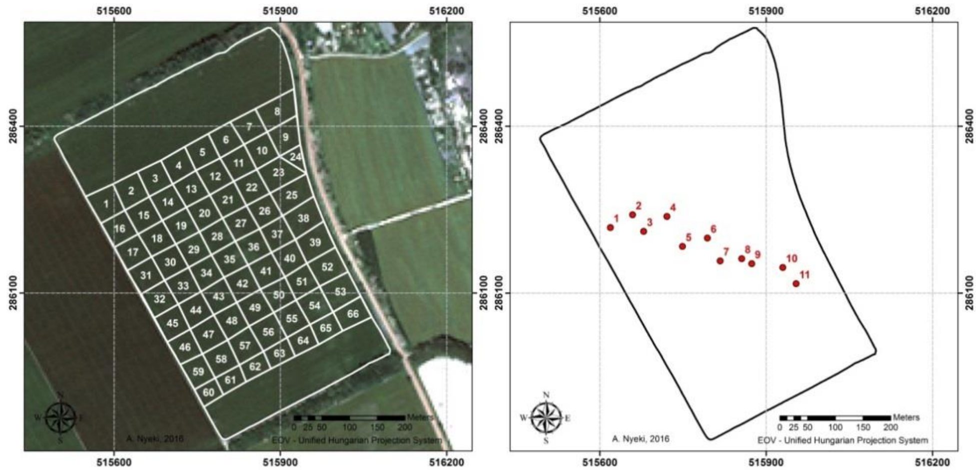
3.1. Results of maize yield predictions

Within the framework of the presented research activity a field level site-specific experiment was established involving a plant physiological decision support model to test the accuracy of the applied system under precision crop production technologies.

The field trials provided possibilities for maize yield predictions in 2010, 2011, 2013, 2014 and in 2015. Firstly, the measured and calculated yields were analyzed at field level, which means that the maize yield was calculated for each management unit (66) individually (Fig. 1a). In spite of applying the decision support system using the results of agrotechnology, meteorology and soil databases for the years listed above, the model's results can only be considered reliable at the field level.

The Ceres-Maize model were estimated under in negative water balance of the growing period in the investigated 11 treatment units; and maize yield were extent over in positive water balance of the growing season systematically. It was predicted over under dry conditions in 2011 and 2015.

The model results' were higher than measured maize yield in extremely rainy year (2010 and 2014). Differences of measured and simulated maize yield were increased (2010, 2014) or decreased (2011, 2015) in the 11 management zones depending clay content of units. The experienced phenomenon is caused by the inaccurate soil physical condition predictions of model. The accuracy of estimation was the most satisfactory in 2013. Maize yield differences were much more balanced in the investigated units than the previously described 4 years.



a, *b,*

Fig. 1. The experimental field with 66 management units (a) and the 11 reference points (b)

3.2. Measurements of soil physical parameters

Soil type

In the selected treatment units (11), soil physical parameters showed certain variability in the soil particle size: clay content has decreased from 16.8% to 8.6% and sand content has increased from 30.6% to ~50%.

Fig. 2 shows that maize yield of selected plots are decreasing in drought year, despite being a year with high precipitation, where yield are increasing depending on clay content (Fig. 3).

Clay content of designated treatment units showed positive linear correlation with maize yield in rainy years (2010 and 2014). This means that results of management zones with higher clay content were higher. According to the results of two wet years a significant connection (R^2=0.5145) was found and there was the same tendency in 2014.

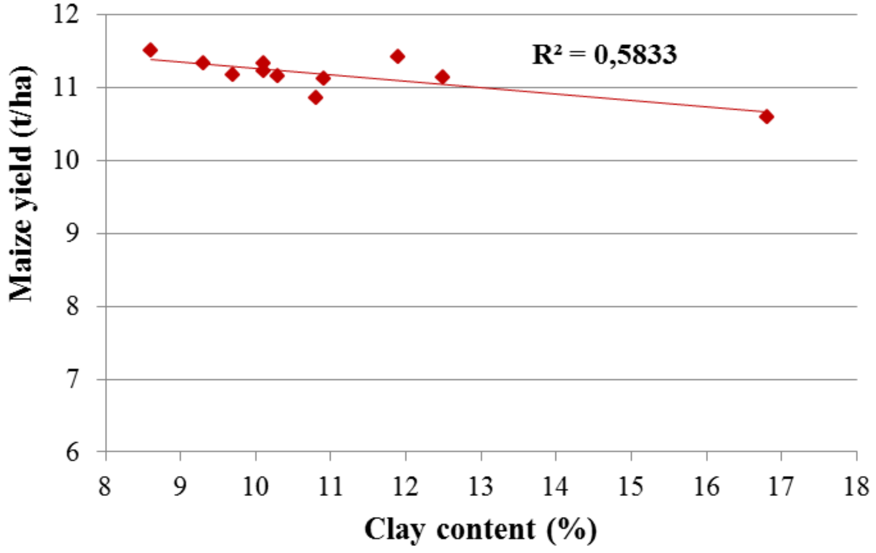


Fig. 2. Maize yield depending on clay content (%) in the reference treatment units (2011– dry year)

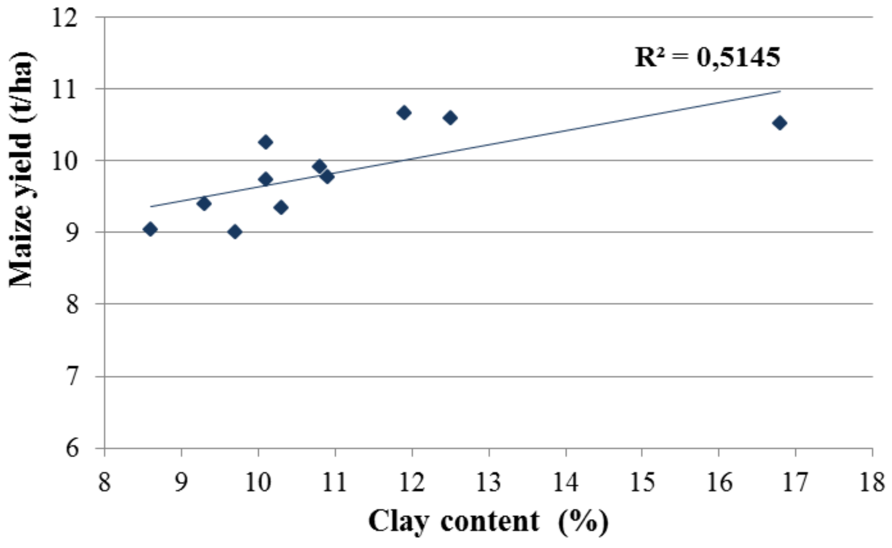


Fig. 3. Maize yield depending on clay content (%) in the reference treatment units (2010- wet year)

The fitting was very similar in case of maize in 2011 and 2015 (dry years) when the tendency was decreased depending on clay content. A statistically justifiable variation was found between the maize yield and the clay content in 2015 (R^2=0.5833).

Penetration resistance

Based on Fig. 4 the tendency was very similar in later years. It can be said that between the penetration resistance and the clay content was positive linear coefficient of determination, R^2 =0.89 in July, 2015.

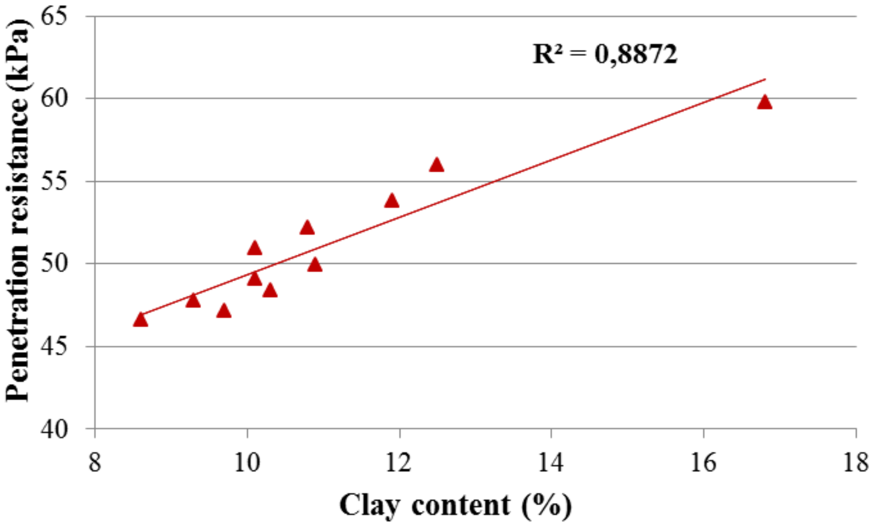


Fig. 4. Coefficient of determination between penetration resistance and clay content (%) in the reference treatment units (2015 – dry year)

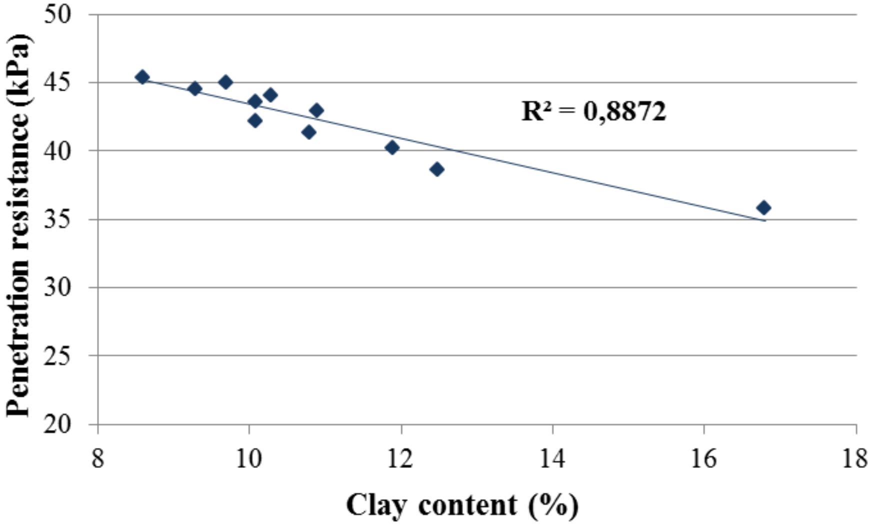


Fig. 5. Coefficient of determination between penetration resistance and clay content (%) in the reference treatment units (2014 – wet year)

Correlations were negative between the penetration measurements and the clay content in August 2014 (Fig. 5) and in November 2013 in the investigated treatment units. Penetration resistance showed strong correlation R^2=0.89.

As a consequence, it can be stated that the strongest relationship was observed between the clay content and penetration measurements in the maize vegetation periods on reference points.

Based on the results of cone penetration that the values were elevated in management zones with higher clay content in 2015, contrasted with cone index in 2014, which were lower.

Fig. 6 and 7 show correlations between the penetration resistance and the soil moisture content (2012 and 2015) in the investigated 11 plots.

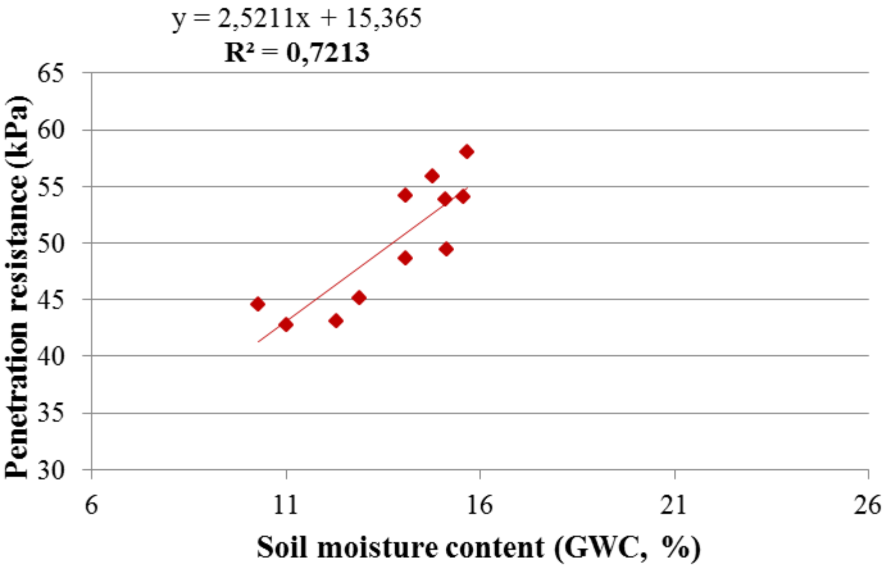


Fig. 6. Coefficient of determination between soil moisture content and penetration resistance (2012 – dry conditions)

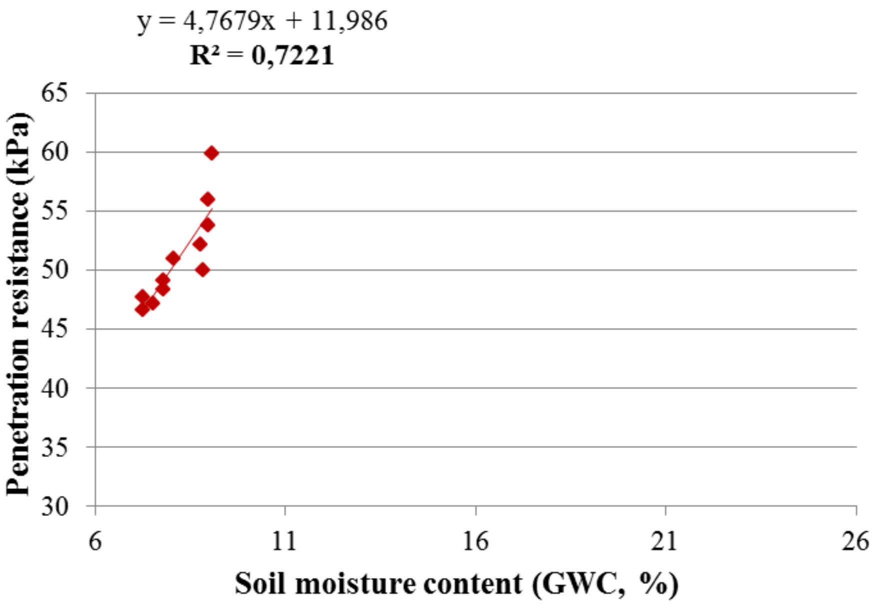


Fig. 7. Coefficient of determination between soil moisture content and penetration resistance (2015 – dry conditions)

Figures also proved a significant close correlation between the factors (2012 – R^2=0.7213; 2015 - R^2=0.7221).

Both figures show a strong positive correlation between variables that the moisture content was increased with increasing CI values. This connection means that higher penetration resistance was recorded in management zones with higher clay content.

Fig. 8 reveals the relationship between the soil penetration measurements and soil moisture content in August 2014. Comparing these databases, the gravimetric moisture content was a significant correlation with CI values (R2 = 0.655).

Increasing soil moisture content - depending on clay content –affected the penetration resistance negatively in the test treatment units. The CI values were reduced contrasted with above mentioned measurements.

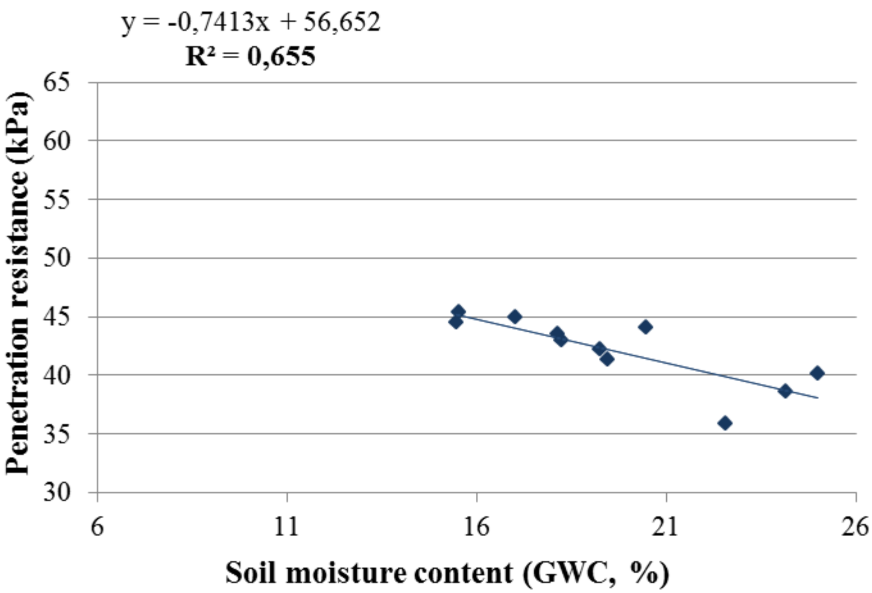


Fig. 8. Correlation between the soil moisture content and penetration resistance (2014 – wet conditions)

In the management zones with higher penetration resistance lower maize yield was measured; in the treatment units with low level of compaction were recorded elevater grain production.

Based on measurements, the values of soil moisture content and penetration resistance were influenced directly in the test treatment units. The experienced phenomenon is caused by the changed soil physical conditions (structure of soil mechanics). Regarding the amount of precipitation there were significant differences in the measuring time.

For examining the soil physical conditions it can be stated that the inaccuracies of decision support model were caused by the effects of soil moisture content and soil texture (clay, silt and sand%). According to the model simulations and the field experiments we can declare that the higher amount of precipitation caused the imprecise estimations of maize fenology and development, respectively (Fig. 9).

Based on this measurement the underestimated values were corrected the cone index of August 2015.

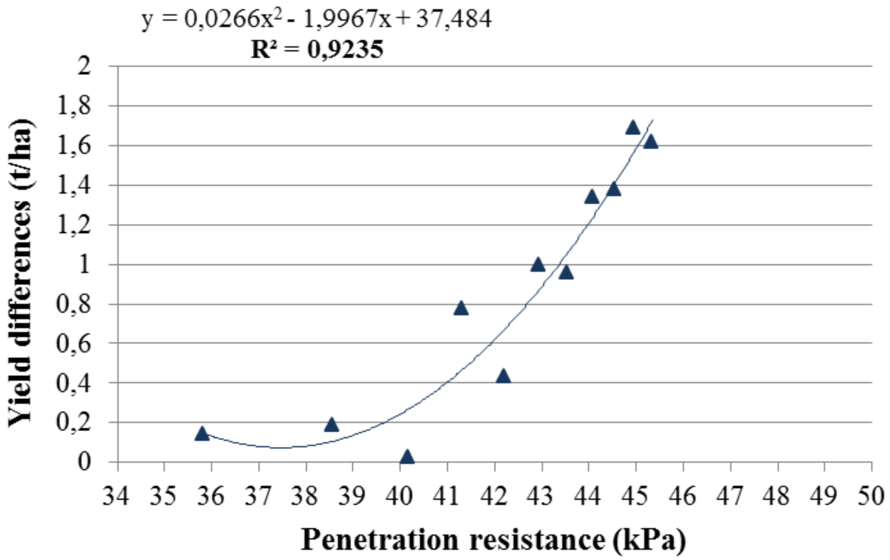


Fig. 9. Differences between measured and predicted maize yield depending on penetration resistance (2014 – wet year)

The differences between measured and simulated maize yield from a year with lower precipitation (2015) shows justifiable correlation with the penetration resistance at lower soil moisture content (2015 – R^2= 0.5252).

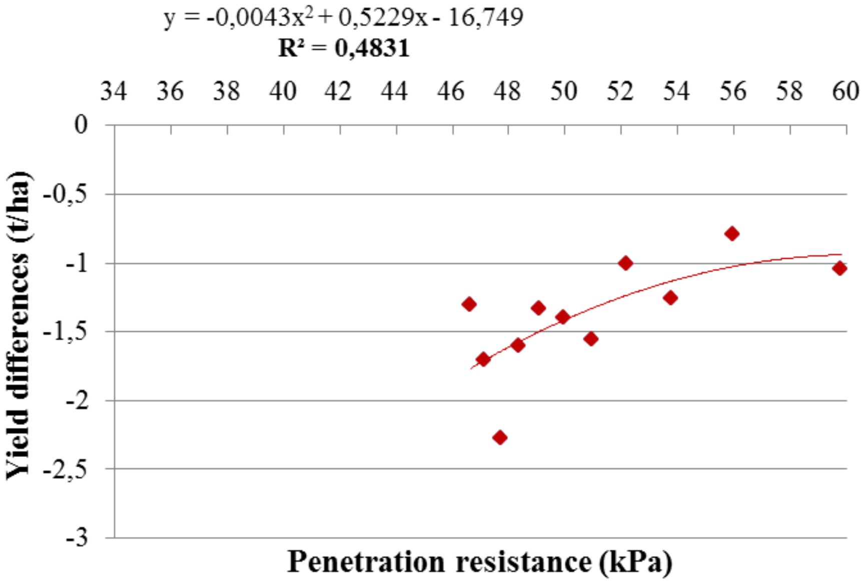


Fig. 10. Differences between measured and predicted maize yield depending on penetration resistance (2015 – dry year)

The apparent soil electrical conductivity

The soil apparent electrical conductivity (EC_a) database of experiment field was compared with the maize yield. EC_a distribution maps, created with values from 0.3 m depth data showed very similar pattern in the study field in each measurement date. The fitting was very similar in case of maps in 2009, 2011 and 2012 (Fig. 11). Strong coefficient of regression was found between the EC_a records and the clay content of reference treatment units in 2009 (R2=0.95). Contrasted with it, the values based on 2011 and 2012 measurements were represented lower connection (2012 - R^2=0.67 és 2011-R^2=0.79).

Between the maize yield and EC_a database was found relationship in the test management zones in all year. Compared the maize yield and EC_a

results in upper 0.3 m soil layer the following regressions were found: data of dry years was given clearly polynomial regression function (2011 - R^2= 0.4851 and 2015 - R^2 = 0.6781) and a similar significance was presented in 2010 (wet year - R^2=0.7408). No significant correlation was found in 2014.

As, in most cases, the EC_a data was mainly affected two factors: soil moisture content and soil clay content (%). Based on this statement and field experiments can proved the hypothesis of dissertation that the topsoil (0.3 m) layer compaction could be detected with EC_a resistance measurements under above mentioned soil types. The measurements accuracy increase only the values belonging to the vegetation period. Therefore, mentioned soil measurements can be successfully applied for decision support systems.

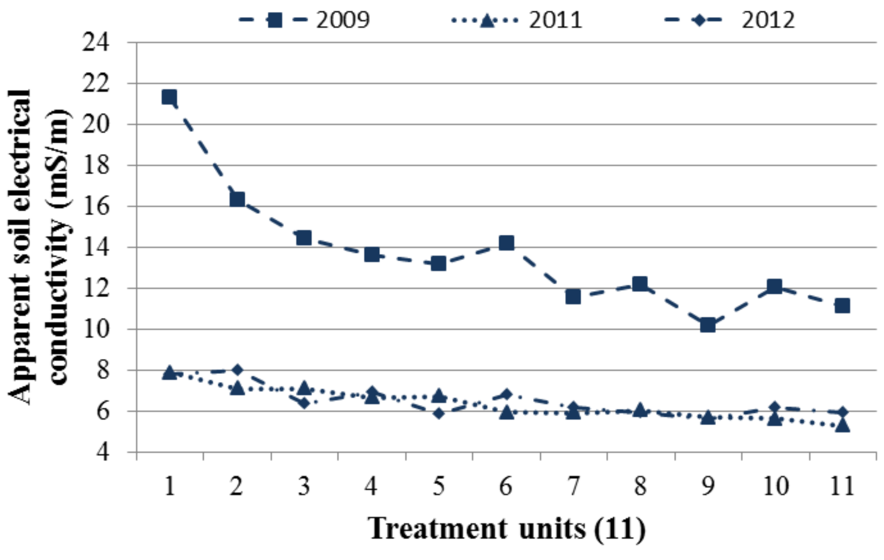


Fig. 11. Characteristics of soil apparent electrical conductivity in the topsoil within the reference management zones (2009, 2011, 2012)

3.3. Characteristics of plant samples

Corn plants with root were collected from 11 test management zones. Plants' height and weight were measured. The correlation coefficient was -0.94 (r) between root weight and -0.64 (r) root length and clay content of treatment units

3.4. Climate change impact on maize yield

We have concluded that for the soil chemical and physical parameters, according to the summarized ranking indexes, the order is P_2O_5, clay content, organic matter content and NO_2-NO_3-N. The investigations clearly indicated that in the case of increasing CO_2, minimum temperature and amount of precipitation an increase in yield can be expected. At the same time, maximum temperature can lead to negative sensitivity with the exception of one climate model in the analysis.

Concerning yield, in the model predicting most critical changes 5.22 mm precipitation compensates for 1ppm CO2 increase, or 1 degree temperature maximum increase compensates for 2.18 degrees temperature minimum increase, similarly 18.56 ppm CO2 increase is compensated for by 1 degree temperature minimum increase.

The sensitivity ranking of maize yield predictions and climate impact test climate parameters of soil parameters was carried out in two climate models based on the results of sensitivity rank row: SMHI BCM-and-ETHZ HadCM3Q.

The model proved effective climate made on the basis of studies and the results of the sensitivity analysis is based on that model sensitivity extends to agyagfrakcióra. The negative impact of climate change on maize can reduce the nutrient supply, but determining its appropriate time and technological conditions for further tests to take.

However, the responses should also be different: change of genotypes and technologies (site-specific soil tillage practices, planting, nitrogen replenishment, variable rate irrigation, etc.).

It seems clear that one of the important possibilities for reducing the effect of climate change on agriculture would be precision irrigation. On the basis of Fig. 12, variable rate irrigation plans can be created. Based on the plant physiological model's results it should be noted that the impact of climate change on maize production is moderately different in the investigated three soil types. Fig. 12 shows that if ETZH-HadCM3Q or MPI-ECHAM5 scenarios occur, most likely the climatic conditions will not be suitable for maize production. Where the KNMI-ECHAM5 scenario occurs, homogeneous irrigation is needed for the same yield level. Concerning SMHI-BCM and KNMI-ECHAM5 models, if precision irrigation is applied – primarily in the case of sandy loam and silt loam soil types – the effect of climate change is moderated practically to zero, e.g. the expected yield remains at the same level.

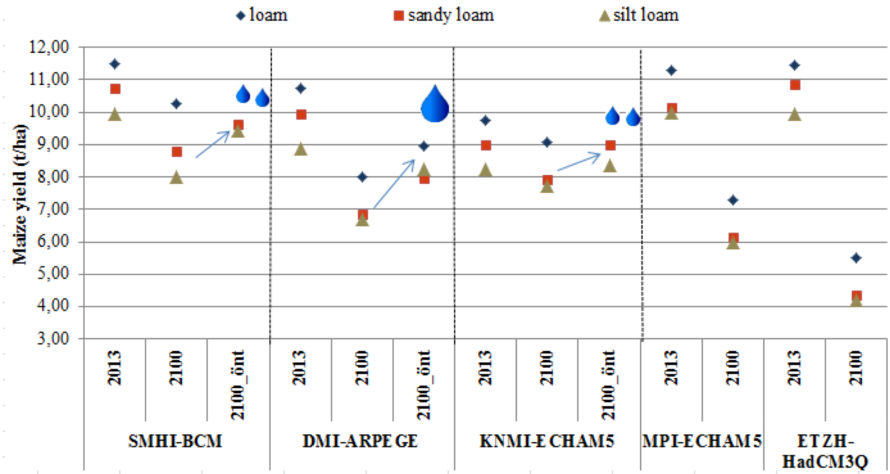


Fig. 12. Predicted maize yield under climate models for 2100 with irrigation applications

4. NEW SCIENTIFIC RESULTS (THESIS)

1. On the basis of maize predictions I have determined to what extent estimates of maize yield will be under the Ceres-Maize model in negative water balance of the growing season on a soil type (8.6 -16.8% clay content and 30.6 - 54.7% sand content); and to what extent will be over the model in positive water balance under defined agrotechnology conditions.

2. I have proved with cone measurements and sensitivity analysis (climate impact test) that the combined changes in soil texture (clay and sand fraction) and soil moisture content cause the differences in the model's inaccuracies.

3. Based on my penetration measurements I can state that the penetration resistance decreases correlatively with higher soil moisture content by the lower clay content values (8.6 -16.8% clay content and 30.6 - 54.7% sand content), despite the CI values' increase with higher clay content by lower soil moisture content.

4. Analyzing the penetration resistance values I ascertain that the soil measurements of maize growing seasons show close correlations with soil texture and maize yield, respectively.

5. On the basis of my investigations I can confirme that the apparent soil electrical conductivity measurements are adequate information's for mapping of site-specific topsoil compaction regarding any kind of soil moisture content on defined soil types.

6. The adapted decision support system and the accuracies of maize yield predictions can be enhanced by precision, site-specific measurements of vegetation period. Consequently, the criteria of

sustainable crop production can be improved by using the precision agriculture technologies.

5. LIST OF PUBLICATIONS

I. ARTICLES

Milics, G. - Kovács, A. J. - Pörneczi, A. - **Nyéki, A.** - Varga, Z. - Nagy, V. - Lichner, L. - Németh, T. - Baranyai, G. - Neményi, M., 2016. Soil moisture distribution mapping in topsoil. Biohydrology (*Accepted*). IF: 1.469

Nyéki, A. – Milics, G. – Kovács, A. J. – Neményi, M. 2016. Effects of soil compaction on cereal yield: review. Cereal Research Communications *(In Press*). IF: 0.607

II. PROCEEDINGS

Nyéki, A. – Varga, Z. – Milics, G. – Kovács, A. J. – Neményi, M. 2012. Nitrogén-ellátás meghatározása a DSSAT (Decision Support System for Agrotechnology Transfer) döntéstámogató modell segítségével. *(Determination of nitrogen supply with DSSAT model)* XXXIV. Óvári Tudományos Nap. Mosonmagyaróvár, Hungary. 5 October 2012. pp. 1-6.

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Independent citations: 1

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Nyéki, A. – Milics, G. – Kovács, A. J. – Neményi, M. 2015. Basic elements of sensitivity analysis of climate change impact special regard to precision maize production. In: M. Neményi; A. Nyéki (Eds.). Proceedings of the Workshop on „Impact of Climate Change on Agriculture”. Mosonmagyaróvár, Hungary. 24 September 2015. pp. 115-120. (ISBN:978-963-359-057-7)

Nyéki, A., Kalmár J., Milics G., Kovács A. J., Neményi, M. 2015. Climate sensitivity analysis of maize yield on the bass of data of precision crop production In: 10th European Conference on Precision Agriculture. Tel-Aviv, Izrael. 12-16 July 2015. pp. 88-91.

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