Theses of university doctoral (PhD) dissertation

IMPACT OF THE TILLAGE SYSTEMS OF MAIZE ON THE CO_2 EMISSION OF SOIL ON THE BASIS OF FIELD EXAMINATIONS

Pappné Törő Ágnes

Associate professor: Dr. Harsányi Endre

UNIVERSITY OF DEBRECEN

Kerpely Kálmán Doctoral School

Debrecen, 2022.

1. BACKGROUND AND OBJECTIVES OF THE DOCTORAL DISSERTATION

The issue of carbon dioxide emissions has long been of interest to many sectors of the scientific community, including agriculture, which is particularly concerned with the amount of carbon dioxide emitted from the soil, the method of measuring it and the possibility of reducing it. Today's major challenges include the reduction of arable land, the degradation of soils, the loss of water resources and the dramatic increase in the world's population, all of which have an intrinsic impact on agriculture. Rising CO_2 emissions are one of the drivers of climate change), as the average surface temperature of the earth has risen by 0.6-0.7°C since the industrial revolution (LAL, 1988; LÁNG, 2005; FARAGÓ, 2009) and the carbon dioxide content of the atmosphere has increased from 280 ppm to 600 ppm (LAL, 1988; LÁNG, 2005).

Under the current circumstances, the agricultural sector is in struggle as a significant proportion of arable land is disappearing due to poor management, urbanization and industrialization.

The key to the agriculture of the future is the development of communication infrastructure. One of the foundations of precision agriculture is the telecommunications system, the construction of which has thus become a priority. With the establishment of agro-information systems, in addition to production, management and organizational tasks will become easier, which will greatly reduce the burden on producers, promote the development and survival of the countryside by increasing employment and achieving the possibility of staying in place.

International agreements on sustainability to curb climate change also affect agriculture. The reduction of carbon dioxide emissions of arable land is significantly influenced by the appropriate choice of tillage method. The application of a soil-preserving cultivation method also plays an important role in terms of environmental protection (BIRKÁS, 2001). Of the tillage methods, the soil-preserving tillage methods contribute the most to keeping organic matter in the soil. Continuous disturbance of the soil, ploughing accelerate the dynamics of gas exchange by making the upper layer looser (GYURICZA et al., 2002). Domestic practice still prefers conventional plough cultivation, which adversely affects CO_2 emissions, but internationally, new and modern soil-friendly cultivation methods are increasingly being used to better fix carbon in soils.

Adequate water supply is also important for productivity. In Hungary, the deficient water supply has a negative effect on the yield. Without proper amount of water, the ability of the plant to absorb nutrients deteriorates. Numerous domestic (NAGY, 2004) and foreign (SPALDING et al., 2001, GEHL et al., 2005) literature deals with the correlation between water, nutrient supply and plant growth and yield. However, there are examples that over-irrigation might also have a negative effect on yield (NAGY et al., 2004). The research of NAGY (1996, 1998, 1999) in a multifactorial long-term experiment shows that irrigation can influence yields by 28%, while GYŐRFFY (1976) does not mention the effect of irrigation among the influencing factors.

The sustainable use of natural resources is facilitated by the so-called land and water management techniques. They favour non-ploughing tillage methods, take better account of natural resources, and prefer to develop and use more resistant varieties for the future. They play a major role in reducing erosion and effectively adapting to future climatic conditions (COMMONWEALTH OF AUSTRALIA, 2015).

1.1 MAIN OBJECTIVES OF THE ANALYSES

The sustainability is influenced by the global climate change. In my research I analysed a smaller part of the global changes as the emission of carbon dioxide of the soil in different tillage methods. My research enlightens how we can create a more sustainable future with less cultivation of the soil; meanwhile we invest less energy to cultivate it.

My topic is elementary important because of the bad practices, therefor my targets are:

- Determination of the daily dynamics of carbon dioxide emissions. Based on this, estimation of the daily amount.
- Analysis of the effect of different tillage practices on soil CO_2 emissions in calcareous chernozem soils. Quantification of the emission rate, estimation of the annual amount.
- Analysis of factors affecting soil CO_2 emissions, specifically soil temperature and soil moisture.
- Effect of irrigation on soil CO_2 emissions.

2. MATERIAL AND METHOD

The experiments were performed on medium-bound, calcareous chernozem soil at the Látókép Experimental Station of the Institutes for Agricultural Research and Educational Farm (AKIT) of the University of Debrecen (N 47 ° 33 'E 21 ° 27'). The Experimental Plant is located in the Loess Plateau of Hajdúság, the soil is loess-based chernozem with a low humus layer. Physical soil type is medium loam. The 0-20 cm layer of the soil has an average pH of 6.6 (weakly acidic) and a humus content of 2.7%. The AL-soluble P_2O_5 content of the cultivated layer shows significant heterogeneity in the area, based on the average value of the 0-20 cm soil layer (133 ppm) it can be classified as moderately supplied, based on the AL-soluble K_2O content (240 ppm).

The experiment was set up in May 2018 in order to examine the changes during the growing season in irrigated and non-irrigated treatments in autumn ploughed, strip and ripped areas. The polyfactorial experiment is in a split-split-plot arrangement, with the main plots showing tillage and irrigation variants without repetition. In the primary sub-plots the maize hybrids are sown with 50-70 thousand plants/ha density, in the secondary sub-plots the fertilizer treatment is randomized in four repetitions. Each tillage block is 0.8 ha in size, which includes an irrigated and a non-irrigated strip. The total non-fertilized is 0.98 ha, the treated area is 1.96 ha. The size of the examined area is 2.59 ha, where each plot is 30 m^2.

Irrigation variant:

$Ö_1$= irrigated

$Ö_2$= non-irrigated

Fertilizer doses:

1. N 0 kg/ha P_2O_5 0 kg/ha K_2O 0 kg/ha

2. N 80 kg/ha P_2O_5 60 kg/ha K_2O 90 kg/ha

3. N 160 kg/ha P_2O_5 60 kg/ha K_2O 90 kg/ha

Type:

Nitrogen fertilizer: 27%-os MAS (Genezis Pétisó)

Phosphorous fertilizer: MAP 12:52 (N:P)

Potassium: KCl (60%)

In the 2018 growing year, maize was sown in complex tillage on 27th April with the technology provided by KITE cPlc.

The polyfactorial experiment is in a split-split-plot arrangement, with the main plots showing tillage and irrigation variants without repetition. In the primary sub-plots, maize hybrids are sown with a plant density of 60-80 thousand plants/ha, and in the secondary sub-plots, fertilizer treatment is randomized in four replicates.

2.1. STATISTICAL ANALYSIS

Statistical analysis was performed in the R statistical environment using RStudio graphical interface and “gplots”, “car” and “agricolae” packages. The graphs were created with Ms Excel 2010.

Due to the biological and environmental variables that often occur in agriculture, the Type I error was chosen to be 5% (alpha = 0.05), thus reducing the probability of committing Type II error. Thus, the differences in the effects between treatments can be detected more accurately.

To investigate the correlation between carbon dioxide emissions, irrigation, tillage and soil temperature values, and irrigation and temperature values, a repeated measurement model was developed based on the example of *Huzsvai and Balogh* (2015). Example code for the repeated measurement model in statistical environment R:

```
modell<-
aov(ismételt_mérési_változó~kezelés1*kezelés2*mérési_időpontok+Error(egyedi_azonosító/
mérési_időpontok)

data=forrás_adatbázis))

summary(modell)
```

Comparison of the mean value of the measured CO_2 values and yield data was performed by the method of least significant difference (LSD), in which the smallest significant difference was determined. In the R statistical environment, degrees of freedom (df) and mean square errors (MSE) can be defined separately for each post hoc test of the repeated measurement model and split-strip analysis of variance, which was performed with the following code for each model individually (HUZSVAI – BALOGH, 2015):

```
df=df.residual(modell$"hiba:hiba")

mse=deviance(modell$"hiba:hiba")/df

LSD <- with(adatbázis, LSD.test(függő_változó, modellből_a_szignifikáns_hatás, df, mse, console = T))
```

A linear regression analysis was performed to examine the correlation between the measured SPAD values and the yield, the code of which in the R statistical environment is as follows:

2.2. PROCESS OF THE EXPERIMENT

The measurements were aimed at examining the carbon dioxide emissions from the soil for works with less soil disturbance.

The measurements were performed with a Testo 535 type measuring instrument, which is an CO_2 measuring device concentration which operates based on the infrared absorption principle. The individual measuring cylinders placed on the ground and equipped with internal ventilation were of the same size, each measuring 11.88 * 25 cm (diameter * height), each having a volume of 2734 cm^3. In 5 cylinders placed side by side on the ground, the value of the initial carbon dioxide concentration was measured for 1 min and the value of the increased amount of carbon dioxide after the 5 min incubation time (*Picture 1*).

The measurements were performed on a weekly basis, in the early morning hours, and the development of the daily dynamics were examined one day a month. Daily dynamics were recorded four times within 24 hours, in the early morning hours (6-7 hours), then in the morning (9-10 hours), in the afternoon (12-13 hours), and in the evening hours (19-20 hours).

Picture 1: On-location photo

Sampling intervals were determined in 5 min based on previous sampling experience. The sampling points were randomly placed in each plot and the cylinders were sunk into the soil to a depth of 5 cm, making sure that the soil was least disturbed at the given points. These points were marked in the row spacing, thus there was no tillage at all at the sampling sites of the strip tillage area. Upon completion of the measurements, the sampling cylinders were cleaned and vented, preparing them for re-measurement.

The carbon dioxide concentration values are given in ppm (parts per million). Significant differences were examined/searched for in the RStudio statistical system.

For that, the combined gas law was used (Boyle – Mariotte, Gay – Lussac, Charles, Avogadro).

$$pV = nRT$$

where:

p is pressure [Pa]

V is volume [m^3]

n is the chemical amount of the gas [mol]

R is the universal gas constant [8,314 J mol^{-1} K^{-1}]

T is the absolute temperature [Kelvin]

Converting the unified gas law, the carbon dioxide emissions per unit area (m^{-2}) and time (h^{-1}) are obtained in grams.

$$F_{CO2} = \frac{\Delta C \; l \; p \; M}{\Delta t \; R \; T}$$

where:

F_{CO2} is the intensity of carbon dioxide emission [g m^{-2} h^{-1}]

ΔC is the change of carbon dioxide concentration [mol mol^{-1}]

l is the height of the measurement cylinder [m]

p is pressure [Pa]

M is the molar weight of carbon dioxide [44,01 g mol^{-1}]

Δt is measurement time [h]

R is the universal gas constant [8,314 J mol^{-1} K^{-1}]

T is the absolute temperature [Kelvin]

A similar formula was used by MEYER et al., 1987; WIDÉN & LINDROTH, 2003, RÁDICS et al., 2013 etc.

2.2.1. Carbon balance of the soil:

The role of agricultural land in the carbon cycle is very significant, which is why it is worth determining whether the land is emitting, absorbing or neutral.

Biomass measurement is a general method of measuring the amount of carbon in an ecosystem. To assess the carbon turnover of agricultural land, the harvest index (HI), i.e. the ratio of useful yield to total aboveground biomass, is inferred, leading to area and crop-specific equations (SMITH et al., 2010).

Most data on yield are available as a result of measurements and various estimates, with root and leaf volumes often calculated as a given fraction of the yield. NPP (net primary production) is taken as 0.45-0.5 times the total dry weight (SMITH et al., 2010).

Another way of calculating NPP is the difference between gross primary production (GPP) and autotrophic respiration (R_{auto})

$$NPP = GPP - Rauto$$

2.2.2. Determination of soil temperature and moisture content

Soil temperature was measured with a TFA LT-101 insertion laboratory thermometer. After one second, the instrument provides an accurate value of the soil temperature between -40 and +200 degrees Celsius, with a basic accuracy of 0.5 ° C.

For the determination of soil moisture content a FIELD SCOUT TDR 300 soil moisture measuring probe was used. The TDR (Time Domain Reflectrometry) method determines the moisture content of the soil based on the rate of propagation of radio frequency electromagnetic waves in the soil. The instrument consists of a moisture measuring head, two 20-20 cm measuring wires and a data acquisition unit. The measurements were performed simultaneously with the measurement of the carbon dioxide concentration.

3. RESULTS

3.1. DEVELOPMENT OF THE DAILY CO_2-DYNAMICS

In the 2 crop years, in June, July, August and September, the development of the daily dynamics of carbon dioxide concentration was measured in a complex tillage experiment. I performed the experiments 3-4 times on the studied days, depending on the weather.

The studies were examined by three-way analysis of variance, in which the time of the measurements, the method of tillage and irrigation, as well as their interactions were compared.

In the scope of the experiment, the change in soil temperature in the daily dynamics was also examined separately. Factors influencing soil temperature results were examined by three-way analysis of variance; the three factors were irrigation, measurement time, and method of tillage. The measurements were performed in parallel with the carbon dioxide concentration measurement.

3.2. STATISTICAL EVALUATION OF CO_2 RESULTS MEASURED IN DAILY DYNAMICS

Examining the emission values of the daily dynamics with the help of two-factor analysis of variance, a significant result was obtained by comparing tillage and measurement time (***Table 1***).

Table 1: Analysis of the effect of tillage and measurement times on daily dynamics using two-factor analysis of variance (Debrecen, 2018-2019)

	Degree of freedom	**The sum of squares of the deviation**	**Variance**	**F value**	**Significance**
Measurement time	3	573.8	191.27	2.856	0.0506
Tillage×measurement time	6	1028.8	171.46	2.560	0.0361 *
Remainder	36	2410.84	66.97		
Significance code: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1					

Examining the daily dynamics with the SNK (Student Newman Keuls) test, the results of the irrigated area differed significantly. The results of the winter ploughed area were significantly ($P < 0.001$) higher except for the afternoon hours than the results of the other two tillage treatments. The highest value was measured in the evening hours (20.21 g m^{-2} d^{-1}), while the lowest value in the winter ploughed area was measured in the afternoon hours (3.66 g m^{-2} d^{-1}). In the case of strip tillage higher values were measured in the morning (5.58 g m^{-2} d^{-1}) and in the evening (6.05 g m^{-2} d^{-1}), the measurement in the morning was the lowest (2.51 g m^{-2} d^{-1}). In the ripped area the lowest values were measured in the morning (3.28 g m^{-2} d^{-1}) and evening (2.3 g m^{-2} d^{-1}), the morning (5.36 g m^{-2} d^{-1}) and the afternoon (3,92 g m^{-2} d^{-1}) measurements exceeded the values of strip tillage, the afternoon measurement (3.92 g m^{-2} d^{-1}) was the highest in the ripped area.

There was a significant difference between irrigated and non-irrigated plots in the ripped area. In the non-irrigated area (5.46 g m^{-2} d^{-1}) the emission was significantly higher than in the irrigated area (3.72 g m^{-2} d^{-1}). When performing the SNK test in a ripped area, there was also a significant difference between the time of day. The highest emission was measured in the morning (6.45 g m^{-2} d^{-1}), while the lowest was measured in the morning (3.36 g m^{-2} d^{-1}), which did not differ significantly from the evening measurement (3.53 g m^{-2} d^{-1}). There was no significant difference between the measurements before noon and at noon either.

Summarizing the results of daily dynamics in terms of temperature, it can be said that in most cases the values increased continuously from morning to evening in both irrigated and non-irrigated areas, the highest values were measured in the evening, most often in the winter ploughed area. Overall, the values of the winter ploughed area were the highest, while the values of the ripped area were the lowest. The values of the strip tillage area were between the two, they rarely exceeded the maximum value of the winter ploughed area. The temperature values of the non-irrigated area were higher than the values of the irrigated area.

3.3. IMPACT OF TILLAGE AND IRRIGATION ON SOIL MOISTURE

The role of tillage in terms of water utilization is unquestionable. Several researchers have demonstrated that water utilization is much more effective with these tillage methods than in traditional tillage methods. GYURICZA (2004) measured positive values in the upper 10 cm layer of the soil, while ERBACH et al. (1992) show a significant difference in the upper 20 cm layer of soil. RÁTONYI (2003) also confirms the moisture-retaining capacity of tillage systems without ploughing.

The results of the post hoc test showed the highest moisture values in the winter ploughed area in both study years, both under irrigated and non-irrigated conditions. Soil moisture content was variable in strip tillage and ripped plots, the same trend was not observed in the two years.

The statistical evaluation of irrigation confirmed that contrary to the findings of the researchers, the highest soil moisture values were measured in the case of the conventional tillage method, and the values of the autumn ploughed area were the highest in both irrigated and non-irrigated treatments. The strip tillage areas and the ripped areas only occasionally exceeded the values of the ploughed area.

3.4. DAILY CARBON DIOXIDE DYNAMICS MEASUREMENTS, 2018

The daily dynamics results of 2018 were averaged and compared with the hourly data from the Precision Crop Research and Development Service Centre of the University of Debrecen, which showed that there was no significant correlation between them, and that the influence of temperature on carbon emissions was low.

The temperature variable and soil moisture separately did not have a significant effect on carbon emissions, but when the two factors were analysed together, significant results were obtained, and by taking these factors into account, carbon emissions could be estimated with reasonable accuracy. In the figure below (***Figure 1***), the black circles are the measured values and the green circles are the estimated values from the model.

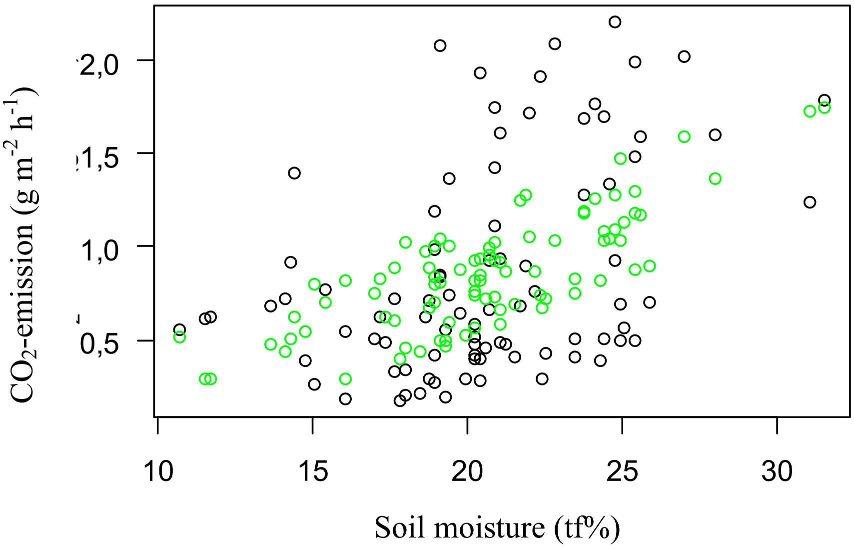

Figure 1: Effects of soil moisture and temperature on CO_2 emission (Látókép, 2018)

Multiple linear regression analysis was performed to examine the effects of soil temperature and soil moisture (***Table 2***), to see how carbon dioxide emissions are affected by these variables. The results showed that soil temperature and soil moisture had a significant effect on carbon emissions.

Table 2: Results of linear regression analysis for estimated CO_2 emissions, 2018

	Estimated value	Standard error	T value	Significance
Intersection	-1.89745	0.49490	-3.834	0.000243 ***
Soil moisture	0.06203	0.01303	4.760	7.99e-06 ***
Soil heat	0.05837	0.1590	3.670	0.000424***

Significance code: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Remnants	Degree of freedom	Multiple R-squares	Aligned R-square	F value	Significance
0.4769	84	0.02935	0.2767	17.45	4.596e-07

The soil temperature and soil moisture data affecting carbon dioxide emissions are shown in a three-dimensional graph (***Figure 2***), which illustrates the effect of the two explanatory variables. Separately, there was no such detectable result for the influencing role of soil temperature and soil moisture, but collectively, carbon dioxide emissions were shown to increase with increasing soil moisture and soil temperature. Since the variables are within a narrow range, the regression plane provides a reasonable estimate of the expected magnitude of carbon dioxide emissions.

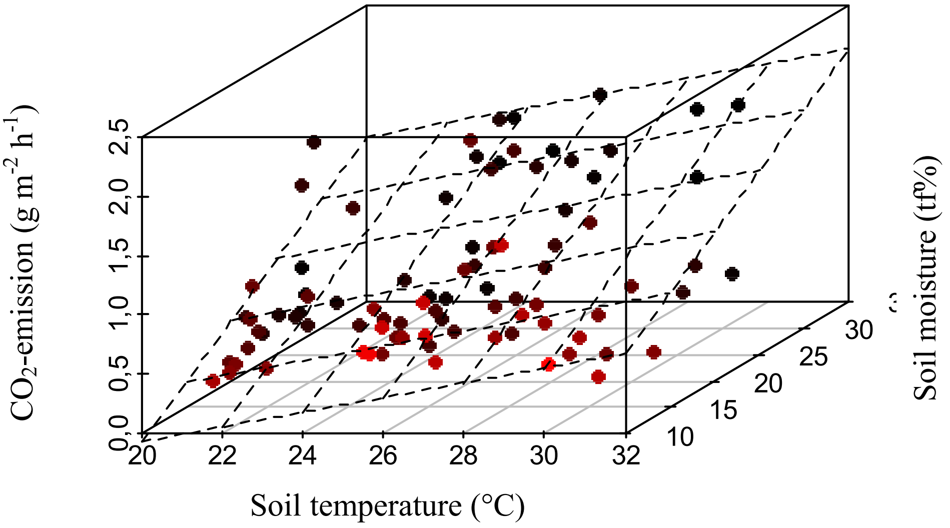

Figure 2: Effects of soil temperature and soil moisture on carbon dioxide emissions (Látókép, 2018)

The daily emissions were significantly affected by the exact time of day and hour of day at which the experiment was recorded (***Figure 3***). In 2018, the highest values were obtained in the months of June and July, in the morning and at noon. In the months of June and July, all daily measurements were basically higher than in the other months studied at different times of the day. The highest of these was obtained in the morning of the June measurement, with a value of 1.87 g m^{-2} h^{-1}. The measurement at 12 noon in July (1.65 g m^{-2} h^{-1}) was significantly higher than the measurement at the other times of the day. The May values were below the values of the other months, with the highest value obtained in the morning measurement (0.4 g m^{-2} h^{-1}), which is the same as the August measurement, when the morning measurement was also the highest (0.68 g m $^{-2}$ h^{-1}).

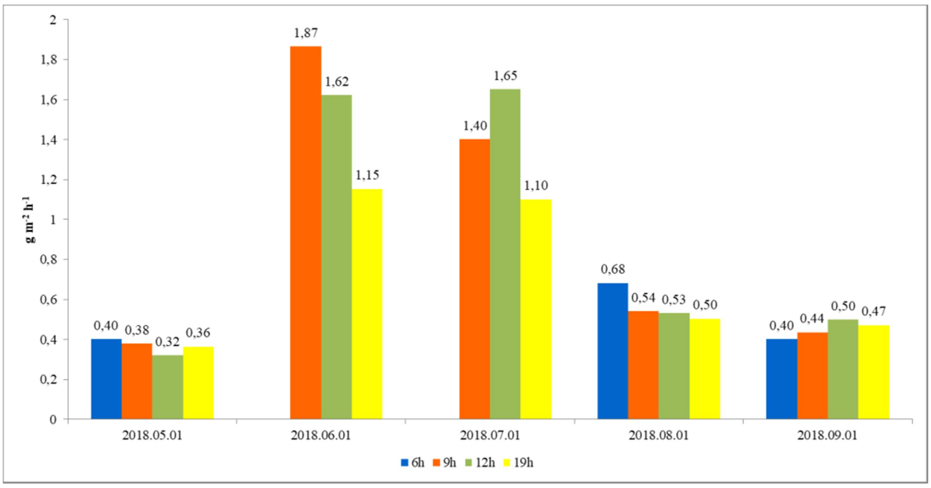

Figure 3: Impact of measurement times on soil carbon emissions (Látókép, 2018)

Based on the hourly 2 m air temperature data obtained from the Centre, carbon dioxide emissions were estimated using a regression model. The model showed that soil temperature and soil moisture had a significant effect on emissions (***Table 3***).

Table 3: Regression model results for estimated CO_2 emissions, 2018

	Estimated value	**Standard error**	**T value**	**Significance**
Intersection	-3.03668	0.94908	-3.200	0.00597 **
Air temperature	0.04596	0.01970	2.334	0.03394 *
Soil moisture	0.13366	0.03805	3.513	0.00314 **
Significance code: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1				

Remnants	**Degree of freedom**	**Multiple R-squares**	**Aligned R-square**	**F value**	**Significance**
0.3827	15	0.5231	0.4595	8.225	0.003877

The black dots in ***Figure 4*** represent the values estimated by the model, while the blue dots are the measured values. It can be seen that there are many coincidences between the measured and the estimated values, with the most striking discrepancy in July, but in the other months - May and August in particular - the measured values match the predicted values.

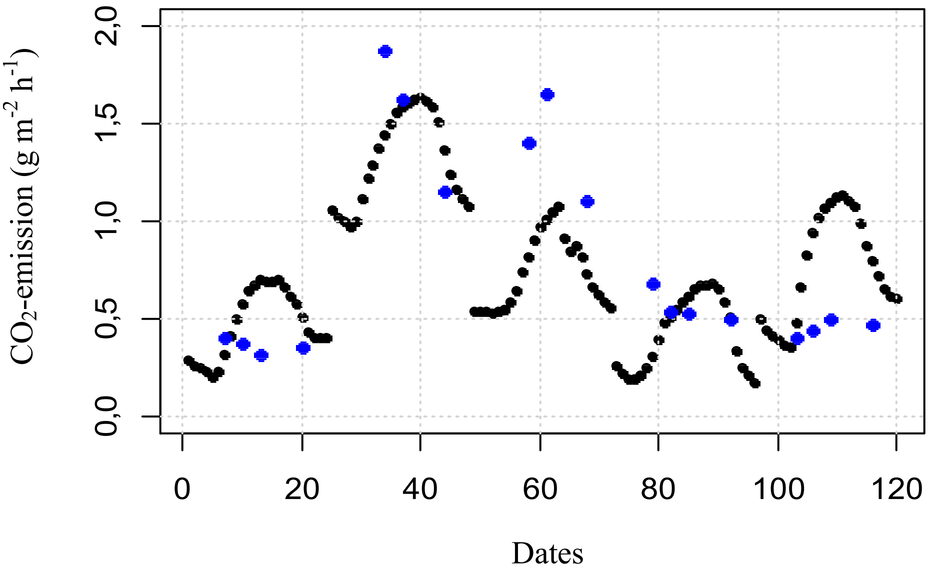

Figure 4: Estimated and measured emission values for hourly air temperature and soil moisture values in the alpine region (Látókép, 2018)

3.4.1. Estimated daily carbon dioxide emissions, 2018

The values estimated by the model are illustrated in ***Figure 5.*** The value measured in June was the highest estimated (31.56 g m^{-2} d^{-1}), which coincides with the measurements of RULÍK (2018) (30.096 g m^{-2} d^{-1}). The values of the other months are below this, most notably the month of August, which was estimated at 10.17 (g m^{-2} d^{-1}) by the model.

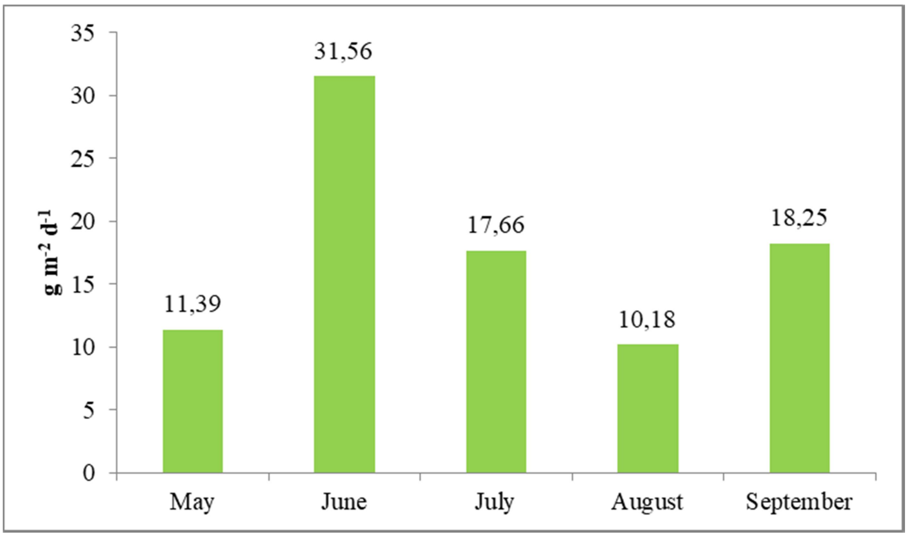

Figure 5: Estimated emissions for the analysed months (Látókép, 2018)

Since the results can be so different based on soil temperature and soil moisture, the question rose, how much the hourly actual measurement should be multiplied to get the daily CO_2 emission? The daily emission values estimated by the model were divided by the hourly values to get the multipliers. ***Figure 6*** shows the 24-hour multipliers for the five measured times.

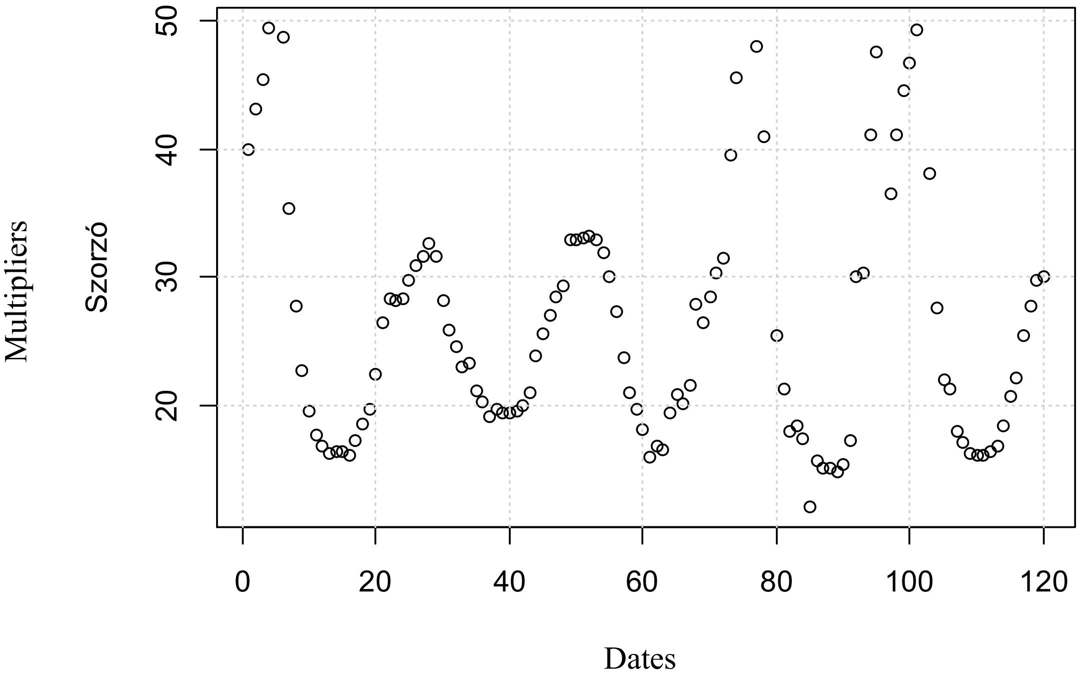

Figure 6: Comparison of dates and multipliers

The multipliers based on the averages of the five days are shown in ***Table 4***.

Table 4: Multipliers (K) for estimating daily CO_2 emissions, 2018

Hour	00	01	02	03	04	05	06	07	08	09	10	**11**	12	13	14	15	16	17	18	19	20	21	22	23
K	36	39	39	40	40	37	32	27	23	21	19	**18**	16	17	17	17	18	19	20	25	27	31	33	30

3.5. DAILY CARBON DIOXIDE DYNAMICS MEASUREMENTS, 2019

The combined effect of soil temperature and soil moisture on carbon dioxide emissions in 2019 is also stronger than their individual modelled effects, but their combined effect is lower than in the previous year. As shown by the green circles, the estimated values are in a narrower range, as are the measured values indicated by the black circles (***Figure 7***).

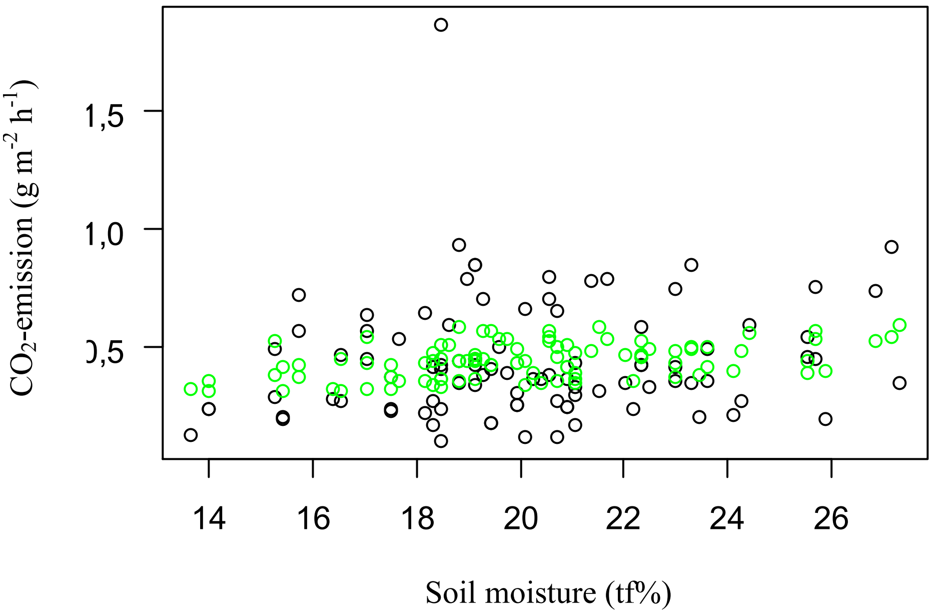

Figure 7: Effects of soil moisture and temperature on CO emission$_2$ (Látókép, 2019)

The combined effect of soil moisture and soil temperature on carbon dioxide emissions already shows a significant relationship. The correlation exists, but it is very weak, with soil temperature and soil moisture affecting emissions by 9% overall (***Table 5***).

Table 5: Linear regression analysis results for carbon emissions, 2018

	Estimated value	**Standard error**	**T value**	**Significance**
Intersection	-0.181243	0.224259	-0.808	0.42104
Soil moisture	0.009009	0.008290	1.087	0.27998
Soil temperature	0.018567	0.006817	2.724	0.00771 **
Significance code: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' ' 1				

Remnants	**Degree of freedom**	**Multiple R-squares**	**Aligned R-square**	**F value**	**Significance**
0.2441	93	0.08965	0.07007	4.579	0.01268

Of the two explanatory variables, only soil temperature was significant. The range of the data was narrower than in the previous year, but the regression plane fits here as well, and can be used to estimate the expected magnitude of carbon dioxide emissions, with an average error of 0.244 g m $^{-2}$h^{-1}. The measured values are close to the grid, with only a few outliers (***Figure 8***).

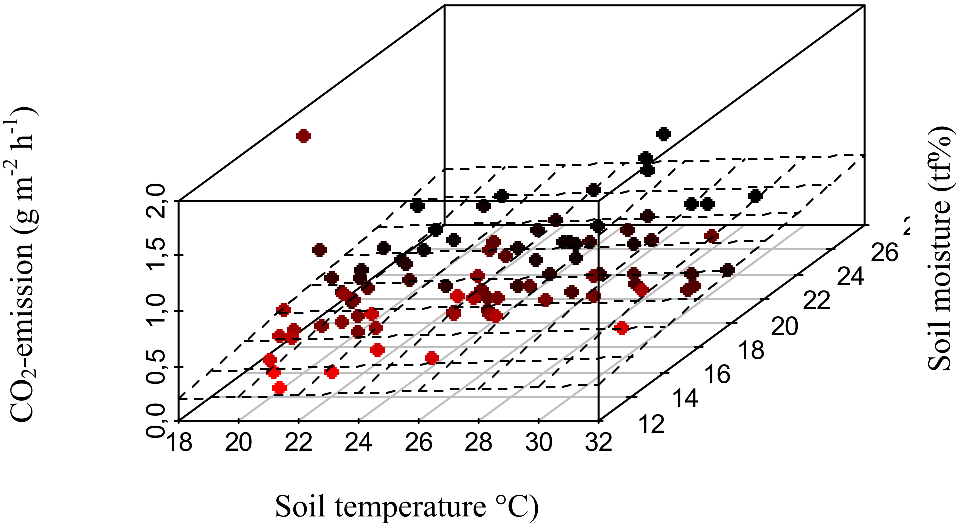

Figure 8: Effect of soil temperature and soil moisture on carbon dioxide emissions

In 2019, emissions were typically highest in June, during all four periods of the day (***Figure 9***). The morning measurement had the highest emission value (0.72 g m^{-2}h^{-1}) in July, while the September measurement had the lowest values overall, with the morning measurement reaching the lowest value of 0.2 g m^{-2} h^{-1}.

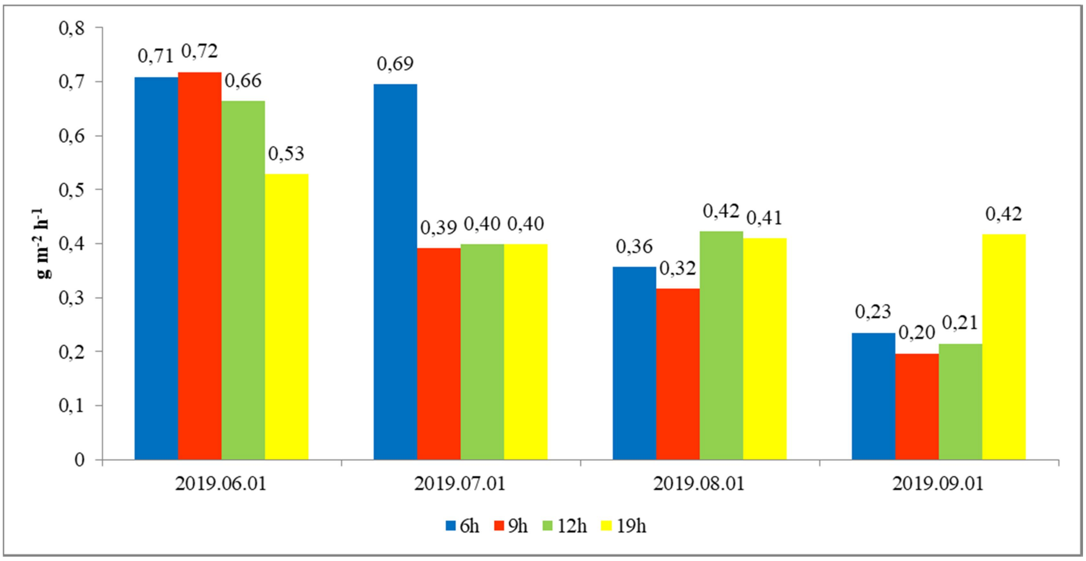

Figure 9: Impact of measurement dates on soil carbon emissions (Látókép, 2019)

Based on the hourly 2 m air temperature and soil moisture data, carbon dioxide emissions can be reasonably estimated. The regression model results are shown in ***Table 6.*** Only the effect of soil moisture was significant at the 10% level,

Table 6: Hourly air temperature results by regression analysis, 2019

	Estimated value	Standard error	T value	Significance
Intersection	-1.001363	0.706976	-1.416	0.1802
Air temperature	0.003200	0.007768	0.412	0.6871
Soil moisture	0.067821	0.033551	2.021	0.0643
Significance code: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1				

Remnants	Degree of freedom	Multiple R-squares	Aligned R-square	F value	Significance
0.1622	13	0.2448	0.1286	2.107	0.1612

Based on the regression model, the curves of the 2019 values are much flatter, the measured values (blue dots) fit the model less well, with the month of July being the month where the model values coincide with the measured values the most (***Figure 10***). In the month of June higher results were obtained, while in the months of August and September the values were below the model. The average error of the estimate was 0.162 g $m^{-2}h^{-1}$.

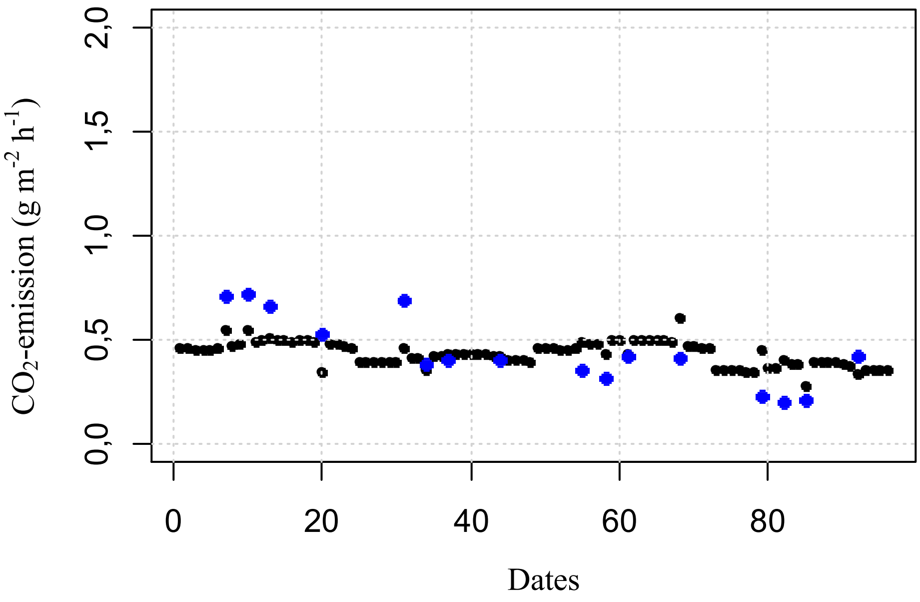

Figure 10: Estimated (black) and measured (blue) emission values for hourly air temperature and soil moisture in the alpine region (Látókép, 2019)

3.5.1. Estimated daily carbon dioxide emissions, 2019

In 2019, analysing the total carbon dioxide emissions, the highest value was obtained in August (11.57 g m^{-2} d^{-1}), which is not significantly different from the value in June (11.54 g m^{-2} d^{-1}). September had the lowest measured value of 8.89 g m^{-2} d^{-1} (***Figure 11***). Comparing the two years, the daily dynamics results for 2019 were below those of 2018 and the same year. RÁDICS measured similar values in 2014 in the areas of Enying and Mesztegnyő.

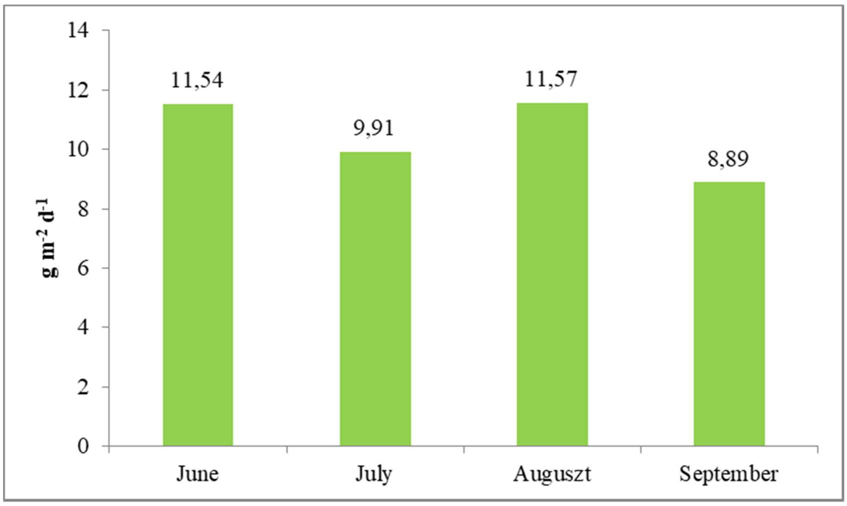

Figure 11: Estimated emissions for the analysed months (Látókép, 2019)

This year it was attempted to determine the multiplication factor to get a realistic figure to determine the daily carbon dioxide emissions. The multiplication factor varied with a lower amplitude than in the previous year, with two extreme values of 21 and 26 (***Figure 12***).

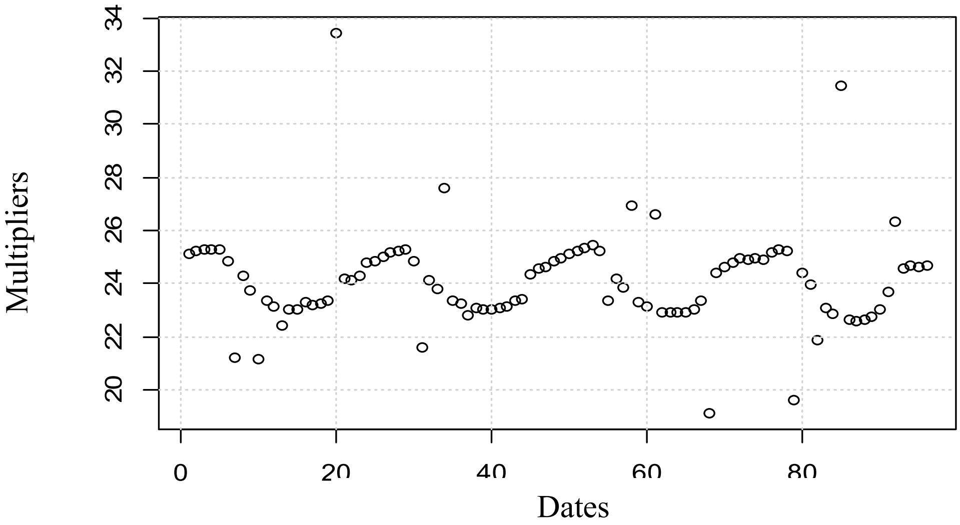

Figure 12: Comparison of dates and multipliers

Table 7: Multipliers (K) for estimating daily CO_2 emissions, 2019

Hour	00	01	02	03	04	05	06	07	08	09	10	**11**	12	13	14	15	16	17	18	19	20	21	22	23
K	25	25	25	25	25	25	21	24	24	24	23	**23**	26	23	23	23	23	23	23	26	24	24	25	25

The daily dynamics data were compared separately with soil temperature and soil moisture. The results of the multiple linear regression analysis show that these two factors have a combined effect on emissions, with almost 30% in 2018 and 9% in 2019. The model with two explanatory variables was valid in all its parameters in 2018, in 2019 only the soil temperature values determined the regression plane.

The hourly 2 m air temperature and soil moisture significantly influenced the hourly emission values. In 2018, the coefficient of determination was 0.52, i.e. 52% of the carbon dioxide emissions were influenced by these two factors. The mean error of the estimate was 0.383 g m $^{-2}$ h^{-1}. Estimated daily emission values were very close to the literature (RULÍK, 2018; KOVÁCS,2018). In 2019, only soil moisture was significant, the influence of air temperature could not be detected. The explanatory power of the model was 24.48%, with an average estimation error of 0.162 g m $^{-2}$ h^{-1}. Lower estimation error was associated with lower measured values.

3.6. ANNUAL DYNAMICS OF CO_2 EMISSIONS

3.6.1. Annual dynamics of CO_2 emissions in 2018

Using the measured CO_2 emission data, we estimated the relationship between 2 m air temperature and emissions using the O'Connell model. Three parameters of the model were determined by nonlinear regression analysis. The final model was as follows:

$$CO_2 = 0,03282e^{0,0364T \quad ,004885T^2}$$

where:

CO_2: emissions per square metre per hour

***T*:** Hourly data of air temperature at 2 metres

This model only takes temperature into account. ***Figure 13*** shows the relationship between air temperature and emissions, where the blue dots are the estimated values and the empty circles are the measured values. The model fits well in all ranges, and the model we use correctly represents the relationship between 2 m air temperature and emissions.

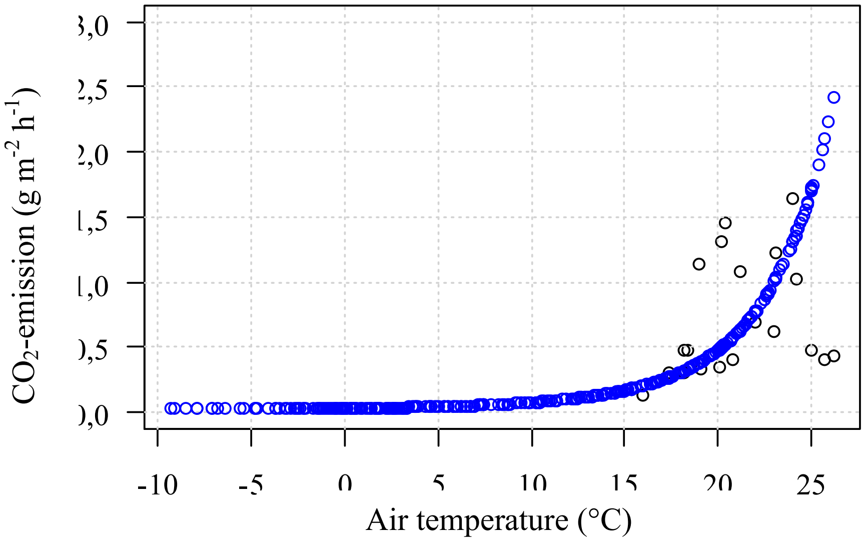

Figure 13: Estimated and measured emissions and air temperature data (2018)

Based on daily temperatures at the experimental site, CO_2 emissions were estimated for each day of the year. ***Figure 14*** shows the annual emission path estimated by the O'Connell model, which shows good agreement with the measured emission values up to 180 days of the year. Thereafter, however, a strong overestimation is observed. The reason for this is that in

Hungary the moisture content of the soil decreases so much in the second half of the growing season that it limits carbon dioxide emissions. During this period, natural soil re-compaction and precipitation gradually seal the soil surface, aerodynamic resistance becomes too high and air exchange is greatly reduced.

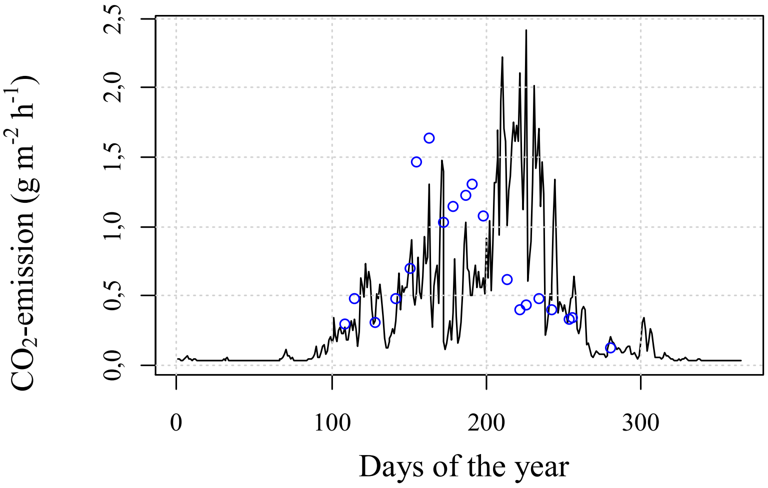

Figure 14: Estimated and measured carbon dioxide values compared to days of the year (2018)

To forecast the annual volume, the hourly values were multiplied by the multiplication factor already estimated. The measurements were taken in the morning, so the multiplier of 18 was used, which was established in 2018. This provides a good estimate to approximate the daily volume. The annual estimate we calculated was 2 274 g m^{-2}, a theoretical value that would occur if moisture and soil sealing did not limit emissions, but in practice, this year, about half of this is a realistic value of 1 137 g m^{-2}. This value is almost one and a half times the value estimated by KUZYAKOV (2006), who estimated 4 000 m^3 of carbon dioxide per hectare. This translates into an annual value of 765 g m^{-2}. However, his estimate is for cooler conditions. In visual terms, the annual CO_2 emission per hectare is about 11 370 kg.

3.6.2. Annual dynamics of CO_2 emissions in 2019

An O'Connell model based on 2018 data was used to analyse the relationship between air temperature and emissions in 2019 (***Figure 15***). The fit of the model was of course not as accurate as in the previous year, as it was tested on "external" data. The measured value was several times below the estimated value and the accuracy of the model deteriorated as the temperature increased. Higher temperatures are in practice associated with lower soil moisture. Low moisture limits the CO_2 emission. at this time. One possibility for further development of the model is to incorporate the effect of moisture. However, this would require continuous soil moisture values, which were not available.

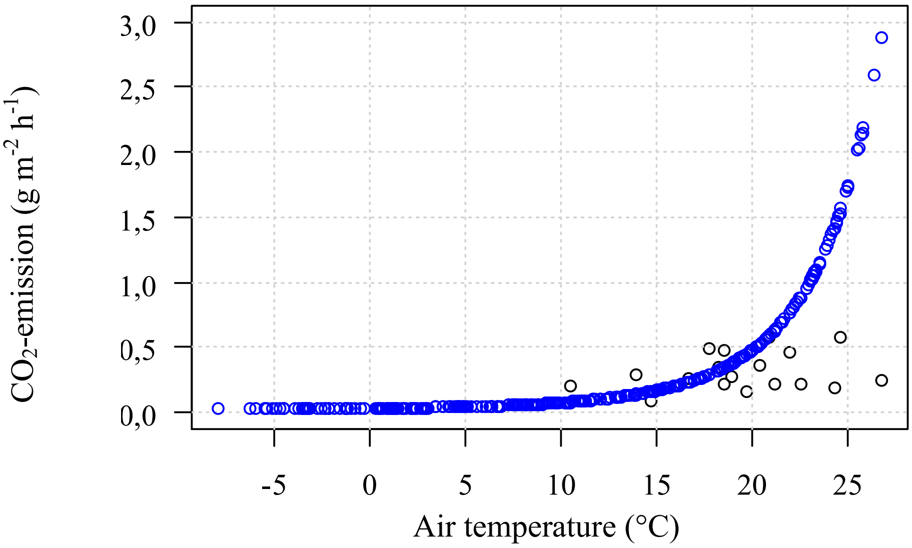

Figure 15: Estimated and measured emissions and air temperature data (2019)

Figure 16, which shows the annual emission values estimated by the O'Connell model, shows that the model overestimates the emission values by a large margin compared to the actual measured values. For 2019, we have also estimated the annual emissions using the 2018 multiplier. The total annual emissions are estimated at 1 978 g m^{-2} y^{-1} using the model. Half of this is 989 g m^{-2} year^{-1}. This is slightly lower than the 2018 value, but closer to the values measured by others. Visually, the annual CO_2 emissions per hectare in 2019 are about 9 890 kg.

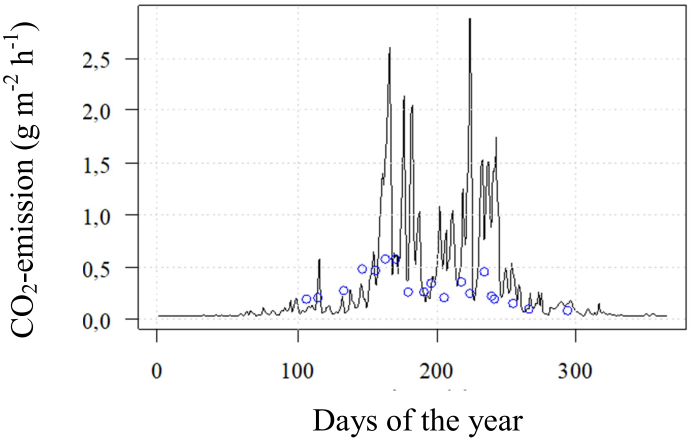

Figure 16: Estimated and measured carbon dioxide values compared to days of the year (2019)

To determine the annual dynamics, air temperature data and emission values were compared using the O'Connell model. In 2018, the model fitted the measured values well, with a larger deviation above 20 °C in 2019.

BIRKÁS et al. (2007) measured carbon dioxide emissions from unploughed soils on hot summer days at 5-8 kg C ha day (2.4 t C ha year^{-1}), strongly influenced by soil moisture and temperature. RAICH and SCHLESINGER (1992) modelled soil respiration on a global scale and found that the most important factor influencing emissions was temperature variation. Annual carbon dioxide emissions reach around 68 ± 4 Pg C y^{-1} according to their research, which is globally correlated with annual air temperature and annual precipitation. The estimate for Hungary (11°C) gives an average of 600 g C m^{-2} year^{-1}. Converted to CO_2 (44/12) this gives 2 200 g CO_2 m^{-2} year^{-1}. This is very close to the theoretical value we estimated in 2018 (2 274 g m^{-2}). Even the theoretical value for 2019 is similar, 1 978 g m^{-2}. Based on these results, our modelled results are in agreement with the values estimated by RAICH and SCHLESINGER (1992). The O'Connell model has drawn attention to the fact that the strongly influencing role of moisture at the experimental site must be taken into account.

4. NEW SCIENTIFIC RESULTS

1. Soil moisture and soil temperature positively influence carbon dioxide emissions. During the growing season, the explanatory power of the model determined by multiple linear regression analysis was 30%. Substituting soil temperature with 2 m air temperature increased the explanatory power of the model to 52%.

2. Among the tillage methods, autumn ploughing resulted in the highest emissions, with an average of 0.78 g m^{-2} h^{-1} in 2018 and 0.35 g m^{-2} h^{-1} in 2019.The lowest emissions were recorded in 2018 in the strip tillage area (0.64 g m^{-2} h^{-1}). In 2019, the measured emissions were the same in the ripped and strip tillage (0.28 g m^{-2} h^{-1}). Based on the measurements of the two years, autumn ploughing is clearly responsible for the highest emission values. Practically no clear difference between strip and fallow cultivation can be detected. The higher emissions were caused by higher soil moisture and temperature in the autumn ploughed plots.

3. The impact of irrigation on emissions is twofold. On the one hand, it increases soil moisture and, on the other hand, it reduces soil temperature. These two effects have opposite effects on emissions, with higher moisture increasing emissions and lower temperatures reducing emissions. The resultant of these two effects can affect emissions differently from year to year.

4. CO_2 emissions are constantly changing, thus to estimate daily values, the actual measurement result must be multiplied by the multiplier depending on the hour of measurement. If measurements are taken at 11 am, a multiplier of 18 is most appropriate.

5. On calcareous chernozem soils, the highest daily carbon dioxide emissions during the maize growing season were estimated in June, with a maximum of 31.56 g m^{-2} d^{-1}. During this period, soil temperatures are already high, but there is still sufficient moisture in the upper soil layer to maintain high soil respiration. In the early summer, the soil surface is not yet closed to a degree that would limit the development of high emissivity values.

6. The O'Connell model was used to estimate the total annual carbon dioxide emissions. Under unlimited rainfall, the maximum value was 19 780-22 740 kg ha^{-1}. In years with average precipitation, 9 890-11 370 kg ha^{-1} are expected.

5. PRACTICAL APPLICABILITY OF THE FINDINGS

The practical implementation of the presented research would help to improve soil life. That is why I deal with carbon dioxide emissions, examining the impact of tillage in order to address the possible factors influencing soil life within an area, and then project them into large-scale cultivation.

Rethinking tillage methods has the potential to improve the above-mentioned soil life. However, preserving biodiversity in our area also raises the issue of organisms that have a detrimental effect on crops. Therefore, it is important to examine our proposals in the light of plant protection, to take into account the plant protection factors that directly and indirectly affect the plant.

It can be stated that due to the activity of soil life and the favourable circumstances, the condition of the plant is also strengthened, which has a beneficial effect not only on the improvement of the yield, but also on the natural resilience of the plant. Natural resistance plays a key role against pests and diseases that reduce crop production. On the other hand, it can be assumed that by preserving biodiversity and slightly disturbing the soil, a suitable environment is provided for pest organisms to reproduce.

New types of tillage can be implemented with less runs and fuel costs, making them more cost-effective for farmers. However, new types of technologies also require new types of machinery, but their investment costs may be returned later, as the use of these technologies does not lead to a loss of yield.

In the future, taking into account sustainability, it is essential that innovations also take place in agriculture in order to protect soils and reduce CO_2 emissions. By using soil-preserving tillage, environment can be favoured in the long run.

The research has shown that the study of carbon emissions, although a long-established area of research, is challenging. The variability of environmental factors such as soil moisture and soil temperature, and other factors that we have not yet analysed, can have a large influence on the values, and therefore a theoretical model is needed that can reliably estimate emissions based on measured environmental parameters.

In the future, for scientific measurements, it is recommended to use more accurate equipment than the TESTO 535.

The O'Connell model describes the relationship between temperature and emission well. It is worth improving it further and incorporating environmental factors that have a decisive influence. It is essential to take into account soil moisture, soil looseness, air pressure and wind speed. Soil looseness and surface sealing could be characterised by the value of aerodynamic drag (s m-1). The proposed model would be very similar to the Penman - Monteith algorithm used to estimate the reference evaporation. This model allows comparisons between different sites, as it uses a hypothetical 12 cm grass, 0.23 albedo and 70 s m-1 aerodynamic resistance for the estimation. Soil organic carbon content and microbial activity must be incorporated into the carbon emission model. These can be supported by previous incubation experiments.

Field experiments have confirmed the effect of temperature and soil moisture in increasing carbon dioxide emissions. Higher humidity and temperature were measured in rotational tillage, and therefore emissions were also higher compared to strip tillage and slack tillage. Thus, reduced tillage systems oxidise soil organic matter significantly slower and release less carbon dioxide into the atmosphere. As such, they can be considered environmentally friendly tillage systems.

Irrigation affects not only crop safety and yield enhancement, but also carbon emissions. Its impact is twofold. On the one hand it increases soil moisture and on the other it reduces soil temperature. These two effects have opposite effects on emissions, with higher moisture increasing emissions and lower temperatures reducing them. The resultant of these two effects can affect emissions differently from year to year. This is confirmed by our experimental results. In 2018, emissions were significantly higher in irrigated plots, but the trend was reversed in 2019. It is worth considering this aspect in the future when assessing the environmental impact of irrigation.

6. REFERENCES

1. *Ellert, B.H. –Janzen, H.H.: 1999.* Short-term influence of tillage on CO2 fluxes from a semi-arid soil on the Canadian Prairies. *Soil and Tillage Research.*Volume 50, Issue 1, 15 February 1999, 21-32
2. *Birkás M. - Jolánkai M. – Stingli A. – Bottlik L.: 2007.* Az alkalmazkodó művelés jelentősége a talaj- és klímavédelemben. *„Klíma-21" füzetek,* 51, 34-47.
3. *Birkás M.:* 2001. A talajhasználat. A talajhasználati módok értékelése. [In: Talajművelés a fenntartható gazdálkodásban. (Szerk.: Birkás M.)] Akaprint Kiadó. Budapest, 99-120.
4. *Commonwealth Of Australia:* 2015. Agricultural Competitiveness White Paper. Canberra.
5. *Erbach, D. C. – Benjamin, J. G. – Cruse, R. M. – Elamin, M. A. – Mukhtur, S. – Choi, C. H.:* 1992. Soil and corn response to tillage with paraplow. *Trans. ASAE.* 35. 1347- 1354.
6. *Faragó T.:* 2013. A nemzetközi fejlesztési együttműködés céljai és a fenntartható fejlődési célok. *Statisztikai Szemle.* 91(8-9): 823–841.
7. *Gehl, R. J. – Scmidt, J.P. – Maddux, L.D. – Gordon, W. B.:* 2005. Corn yield response to nitrogen rate and timing in sandy irrigated soils. *Agron. J.* 97: 1230-1238.
8. *Győrffy B.:* 1976. A kukorica termésére ható növénytermesztési tényezők értékelése. *Agrártudományi Közlemények.* 35:239-266.
9. *Gyuricza Cs. – Birkás M. – Jóri J. I.:* 2002. Művelési rendszerek hatása a talaj CO_2 kibocsátására (Tillage-induced CO_2 emission from soil). [In: Innováció, a tudomány és a gyakorlat egysége az ezredforduló agráriumában. 2002 április 11-12. (Szerk. Jávor A. & Pepó P.)] SZIE–DE ATC KIADVÁNY, Debrecen. 57-62.
10. *Gyuricza Cs. – Liebhard P. – Rosner J.:* 2004. Talajökológiai tényezők vizsgálata talajművelési tartamkísérletekben [In: Birkás M., Gyuricza Cs. (szerk.) Talajhasználat. Műveléshatás. Talajnedvesség.]. SZIE, Gödöllő.
11. *Huzsvai L. – Balogh P.:* 2015: Lineáris modellek az R-ben, Seneca Books http://seneca-books.hu/doc/Linearis_modellek.pdf
12. *International Food Policy Research Institute (IFPRI)*: 2013. 2012 Global Food Policy Report. Washington DC, USA.

13. *Kovács Gy.:* 2014. Mezőgazdasági hasznosítású talajok szén-dioxid-emissziójának vizsgálata Karcag térségében. Doktori Disszertáció. Debrecen.
14. *Kuzyakov. Y.*: 2006. Sources of CO_2 efflux from soil and review of partioning methods. *Soil Biol Biochem*. 38 (3) 425−448.
15. *Lal, R.*: 1989. Conservation tillage for sustainable agriculture: tropic versus temperate environments. *Advances in Agronomy*. 42.: 85-197.
16. *Láng I:* 2005. Idõjárás – éghajlat – biztonság Változás – Hatás – Válaszadás – a VaHaVa projekt – Bevezetõ gondolatok a klímaváltozás kockázatához. *A Magyar Tudományos Akadémia folyóirata*. 166. 7.
17. *Meyer, W. S. – Reicosky, D. C. – Shell, G. S.:* 1987. Technical Report No. 5. Centre for Irrigation and Freshwater Research. Griffith, Australia
18. *Nagy J.:* 1996. Az öntözés és a talajművelés kölcsönhatása a kukoricatermesztésben. *Növénytermelés*. 45: 389-398.
19. *Nagy, J. – Rátonyi, T. – Sulyok, D. – Huszvai, L.:* 2004. Effect of fertilization on the yield of maize (Zea mays L) in different years. [In: George J. Halasi-Kun ed. Pollution and Water Resources Vol.: XXXV. Global Warming and other Central European Issues in Environmental Protection. 2003-2004]. 93-103.
20. *Nagy, J.:* 1998. Interaction between fertilization and soil cultivation in maize production. *Acta Agron. Hung*. 46. 4: 698-705.
21. *Nagy, J.:* 1999. Evaluation of iteraction between irrigation and soil cultivation in maize production. Acta Agron. Hung. 47. 2:181-190.
22. *Rádics J. P. – Jóri J. I. – Fenyvesi L.:* 2015. A talajművelés hatása a talaj CO_2-kibocsátására. [In.:Madarász B. (szerk.) Környezetkímélő talajművelési rendszerek Magyarországon. MTA CSFK FTI.] Budapest. 86-103.
23. *Raich, J. W. – Schlesinger, W. H.*: 1992. The global carbon dioxide flux in soil respiration and its relationship to vegetation and climate. *Tellus B.* 44 (2) 81–99.
24. *Rastogi, M. – Singh, S. – Pathak, H.*: 2002. Emission of carbon dioxide from soil. *Current Science.* 82: 510-517.
25. *Rátonyi T. – Huzsvai L. – Nagy J. – Megyes A.:* 2003. Talajvédő termesztéstechnológiai rendszerek értékelése. [In.: Nagy J. (szerk.) Kukorica hibridek adaptációs képességének és termésbiztonságának javítsa] DE ATC, Debrecen. 141-148.

26. *Saw, Min – Martin, Rulík*: 2020. Comparison of Carbon Dioxide (CO_2) Fluxes between Conventional and Conserved Irrigated Rice Paddy Fields in Myanmar. *Sustainability*. 2020, 12, 5798; doi:10.3390/su12145798.
27. *Spalding, R. F. – Watts, D. G. – Schepers, J. S. – Burbach, M. E. – Exner, M. E. – Poreda, R. J. – Martin, G. E.:* 2001. Controlling nitrate leaching in irrigated agriculture. J. *Environ. Qual.* 30: 1184-1194.
28. *Wattenbach, M. – Sus, O. – Vuichard, N. – Lehuger, S. – Gottschalk, P. – Li, L. – Leip, A. – Williams, M. – Tomelleri, E. – Kutsch, W. L. – Buchmann, N. – Eugster, W. – Dietiker, D. – Aubinet, M. – Ceschia, E. – Béziat, P. – Guenwald, T. – Hastings, A. – Osborne, B. – Ciais, P. – Cellier, P. – Smith, P.:* 2010. The carbon balance of European croplands: A cross-site comparison of simulation models. *Agriculture, Ecosystems & Environment.* 139(3): 419–453.
29. *Widén, B. – Lindroth, A*. 2003. A calibration system for soil carbon dioxide-efflux measurement chambers. *Soil Science Society of America Journal*. 67. 327–334.
30. *Wiggins, S.:* 2016. Agricultural and rural development reconsidered: A guide to issues and debates. From: IFAD Research Series (Issue 1)Publisher: International Fund for Agricultural Development (IFAD). Letöltve: 2020.03.02. https://go.gale.com/ps/anonymous?p=AONE&sw=w&issn=&v=2.1&it=r&id=GALE%7CA577953545&sid=googleScholar&linkaccess=fulltext

UNIVERSITY of DEBRECEN

UNIVERSITY AND NATIONAL LIBRARY
UNIVERSITY OF DEBRECEN
H-4002 Egyetem tér 1, Debrecen
Phone: +3652/410-443, email: publikaciok@lib.unideb.hu

Registry number:	DEENK/369/2020.PL
Subject:	PhD Publication List

Candidate: Ágnes Pappné Törő
Doctoral School: Kálmán Kerpely Doctoral School
MTMT ID: 10067003

List of publications related to the dissertation

Hungarian scientific articles in Hungarian journals (2)

1. **Törő, Á.**, Ragán, P., Harsányi, E.: A szántás és a lazítás hatása a CO2 emisszióra kukorica talajon.
   Növénytermelés. 69 (4), 1-15, 2020. ISSN: 0546-8191.

2. **Törő, Á.**, Tamás, A., Vántus, A., Rátonyi, T., Harsányi, E.: Az emelkedő szén-dioxid kibocsátás és annak összefüggései a mezőgazdasággal.
   Agrártud. Közl. 72, 197-201, 2017. ISSN: 1587-1282.

Foreign language scientific articles in Hungarian journals (2)

3. **Törő, Á.**, Ragán, P., Rátonyi, T., Harsányi, E.: Examinations of the carbon dioxide emission of the soil in the case of different tillage methods in a field experiment.
   Agrártud. Közl. 74, 209-2012, 2018. ISSN: 1587-1282.
   DOI: http://dx.doi.org/10.34101/actaagrar/74/1693

4. **Törő, Á.**, Tamás, A., Rátonyi, T., Harsányi, E.: Effects of soil tillage systems and fertilization on the CO2 emission of chernozem soil.
   Columella. 4 (1), 65-68, 2017. ISSN: 2064-7816.
   DOI: http://dx.doi.org/10.18380/SZIE.COLUM.2017.4.1.suppl

Foreign language scientific articles in international journals (1)

5. **Törő, Á.**, Harsányi, E.: What is the Connection between Soil Carbon Dioxide Emission, Global Warming and Food Security?
   Eur. J. Sustain. Develop. 8 (5), 21-28, 2019. ISSN: 2239-5938.
   DOI: http://dx.doi.org/10.14207/ejsd.2019.v8n5p21

Foreign language abstracts (2)

6. Mohammed, S., Mirzaei, M., **Törő, Á.**, Manouchehr, G. A., Harsányi, E.: Tracking CO2 Emission from Tow Agricultural Lands under Maize cultivation in Two Different Climate Regions.
   In: ICOS Belgium Science Conference : Book of abstracts, Antwerp University, Antwerp, 30-31, 2019.

7. Rátonyi, T., Ragán, P., Duzs, L., Nagy, J., Sulyok, D., Vántus, A., **Törő, Á.**, Fejér, P., Vasvári, G., Harsányi, E.: The Effect of Conventional and Conservation Tillage Systems on Maize Yield. In: XV European Society for Agronomy Congress; ESA2018. Ed.: Christoph Carlen, MDPI AG, Geneva, 128, 2018.

List of other publications

Foreign language scientific articles in Hungarian journals (1)

8. Tamás, A., **Törő, Á.**, Balla, Z., Rátonyi, T., Harsányi, E.: Effects of carbon dioxide concentration on chlorophyll fluorescence of peas "Pisum sativum L.". *Columella. 4* (1), 149-152, 2017. ISSN: 2064-7816. DOI: http://dx.doi.org/10.18380/SZIE.COLUM.2017.4.1.suppl

Foreign language conference proceedings (1)

9. Ragán, P., Harsányi, E., Nagy, J., **Törő, Á.**, Vántus, A., Csatári, N., Rátonyi, T.: Examining the relationship between SPAD, LAI and NDVI values in a maize long-term experiment. In: Proceedings of the 14th International Conference on Precision Agriculture, The International Society of Precision Agriculture, Montreal, Quebec, Canada, 1-4, 2018.

Foreign language abstracts (3)

10. **Törő, Á.**, Harsányi, E.: The effect of soil carbon dioxide emission on the food security - practical aspects of soil cultivation methods. In: Abstract book of the 18th Alps-Adria Scientific Workshop. Ed.: Zoltán Kende, Csaba Bálint, Viola Kunos, Szent István Egyetemi Kiadó Nonprofit Kft., Gödöllő, 162-163, 2019. ISBN: 9789632698182

11. Ragán, P., Duzs, L., Dorogi, Z., **Törő, Á.**, Rátonyi, T.: The effects of the soil tillage and the fertilization on the NDVI values of the maize plant. In: Abstract book of the 18th Alps-Adria Scientific Workshop. Ed.: Zoltán Kende, Csaba Bálint, Viola Kunos, Szent István Egyetemi Kiadó Nonprofit Kft., Gödöllő, 132-133, 2019. ISBN: 9789632698182

12. **Törő, Á.**, Balla, Z., Harsányi, E., Rátonyi, T.: Analysis of maize hybrid yields in a long-term field experiment.
    In: Abstract book : 17th Alps-Adria Scientific Workshop. Ed.: by Kende Zoltán, Szent István Egyetemi Kiadó Nonprofit Kft., Gödöllő, 64-65, 2018. ISBN: 9789632697345

The Candidate's publication data submitted to the iDEa Tudóstér have been validated by DEENK on the basis of the Journal Citation Report (Impact Factor) database.

03 December, 2020