

**Theses of Doctoral (PhD) Dissertation**

**COMPLEX EXAMINATION OF THE EFFECTS OF LAND LEVELLING BY  
SCRAPING ON THE SOIL STATUS**

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# 1. ANTECEDENTS AND OBJECTIVES OF THE DOCTORAL DISSERTATION

One of Hungary's most valuable natural resources is arable land, which is essential for agricultural production and has a significant impact on the country's economy. The success or failure of the agricultural sector affects all levels of society, as it has traditionally provided livelihoods, economic development and prosperity for the regions concerned. For agricultural activity to be sustainable in the long term, it is essential to maintain soil fertility, which requires regular monitoring of soil conditions.

Soil quality can be determined on the basis of its cultivability, suitability for crop production and environmental impact. Optimal soil conditions provide conditions under which crop production can be carried out with a high degree of safety, while the processes taking place in the soil do not damage the environment (Reynolds et al., 2002). If crop production is only possible with significant agrotechnical interventions, the soil is considered to be in an unfavourable condition, which may indicate physical, chemical or biological problems (Birkás, 2006).

Soil degradation, especially soil structure degradation, has become a global problem (Wibaux, 2024). In Hungary, especially in the Tiszántúl region, climate change and agricultural policy regulations have reduced the time available for proper soil cultivation. In order to reduce soil degradation, it is necessary to develop a 3D terrain model of soils, which will provide an accurate picture of the necessary land forming interventions. Surface run-off on compacted soils contributes to inland flooding, leading to reduced yields and loss of cultivation.

In our country, both drought and inland flooding threaten agricultural production. Due to the hydrogeographic characteristics of Hungary, inland flooding is a major problem, especially in the Great Plain, which can occur several times a year (Szesztay, 2000; Pálfai, 1994; Bárdos and Muhoray, 2012). The area of land at high risk of inland flooding is about 530 thousand hectares (Körösparti et al., 2022.). Climate change is increasing the frequency and severity of extreme weather events, such as inland flooding, especially in the poorly permeable, high clay soils of the Great Plain (Birkás et al., 2009).

The development of inland water is essentially determined by soil conditions, geological characteristics, and topography (Bozán et al., 2008). Addressing the problems requires complex amelioration and agrotechnical interventions, such as soil improvement, deep loosening or land forming involving a complete transformation of the topography (Thyll et al., 1983; Ligetvári et al., 2004).

In my research, I have taken a novel approach to soil degradation problems, with a special focus on soil surface roughness. The objectives of my research were defined as follows:

- Preparation of a 3D topographic model of the undisturbed ground, based on which the measurement points can be selected.
- Investigating the effectiveness of differentiated soil management based on precision tools.
- Analysing the effects on the physical and chemical condition of the moved soil and the yield of the crop.

## 2. RESEARCH METHODS

### Characterisation of the study area

Of the total plant size of the Zsadány Malom 97' Kft., 900 hectares are arable land, the crops grown are sunflower, maize, wheat, and medick, Italian rye-grass and Sudan grass needed for the production of feed for the 500 dairy cattle herd. The company was founded in 1997 and its main activity is dairy cattle breeding (URL 2024b). Zsadány is a settlement in the Berettyó-Kőrös region, in the Kis-Sárrét district of the Great Plain.

They are constantly improving their machinery and the technologies they use, including precision farming, differentiated fertilizer application based on soil tests, and the introduction of differentiated sowing in the near future. However, the main obstacle to their development is inland flooding. More than half of their arable land is affected by inland flooding. Of these 500 hectares, more than 30% are under water during agricultural work, which means that they are practically out of production. Because of the constant demand for animal feed, such an area cannot be left unused, so they have started to improve the flooded fields. Initially, they tried soil loosening for several years, but the desired results were not achieved. They then decided to try a more effective method, using a GPS-guided scraper. They aimed to develop a crate control system that could use a GPS signal to bring the soil level in inland water-stricken areas. A software and related technology developed by Trimble seemed to be the best solution, which had not been used in Hungary before, but preliminary information suggested that it could do the job.

The study area comprises three plots (T8, T9, T10). The climate of the sub-region is moderately warm, with an average annual rainfall of 540-560 mm. The topography of the area is low-lying plain. The surface cover is composed of hydromorphic soils, with about 44% of soils being saline, 34% meadow, and 14% cast soils (Dövényi, 2010).

The study area has been under arable cultivation for decades. Until 2014, the fields were cultivated with conventional ploughing, then in 2014, they were converted to reduced (conservation) tillage. The aim was to preserve soil organic carbon. Since 2015, two main tools have been used for tillage: the Horsch Tiger tillage cultivator, which works at a depth of 30-35 cm before sowing spring crops, and the Vaderstad TopDown universal cultivator, which works the soil to a depth of 25-30 cm before sowing autumn crops. Due

to intensive NPK fertilisation, the yields of the crops grown on the plots tested are extremely high, reaching 150-180% of the county average.

Initially, the system was tested on a 2-hectare area, but the first results were promising, with soil levelling presenting a rather impressive result. Then, in 2020, the intervention was extended to a 23.3-hectare site (T8). The T8 site was chosen because it was one of their worst areas and had the largest level differences. The work involved moving around 26,000 cubic metres of topsoil. This plot was left to rest for a year after the earth moving. The next area was marked out on a 40-hectare board (T9), which is also susceptible to inland water. Before scraping, 9 samples were taken from the 0-30 cm soil layer in plot T8, 21 samples in plot T9 and 16 samples in plot T10.

### **Description of the earth mass distribution technique used**

A scraper is a machine made up of a shearing box that cuts and collects soil as it goes. The bottom plate of the box is fitted with a cutting-edge holder to which a steel cutting edge is attached. A hydraulic swinging door closes the cutting box, which is raised and lowered hydraulically by the travelling mechanism. The front of the machine is shaped like a gooseneck and is attached to the tractor, while the rear has an axle fixed by a sliding block. There are towed and self-propelled types available.

A Bos Scraper MEGA with a working width of 3 m, a blade height of 1.25 m, and a cutting box capacity of 7 m<sup>3</sup> was used in the study area. The machine was powered by a 390 hp Fendt 939 Vario tractor. Trimble software was used for control and data processing.

Trimble Ag software provides a quick and accurate picture of spatial heterogeneity and problematic table areas. It is compatible with a range of manufacturers' tools and can identify factors that inhibit plant growth, such as soil compaction or low pH. The software can be used to determine the right strategy, and in addition to levelling the surface, parameters such as the slope and direction of the land can be set to ensure that rainwater reaches the drainage channels in the field.

Trimble Ag software was also used to produce the topographic maps and analyse the spatial data, while Microsoft Excel was used to organise the geological data. Statistical

analyses were performed using a paired two-sample t-test to show the effect of each intervention, and the results were tested using an LSD test.

In preparation for the study, 26,000 m<sup>3</sup> of soil had to be moved over a 23-hectare plot. As a result, a difference in level of 60 cm was measured between the treated and untreated parts of the plot. The untreated area on the left was lower than the filled area on the right (*Figure 1*).



*Figure 1.* Differences in soil levels at the junction of the different slabs

## Methods used in the study

### *Classification of sampling points*

Sampling points were designated on all three surveyed plots: 21 on plot T8, 19 on plot T9 and 16 on plot T10 (*Table 1*).

*Table 1.* Number of sampling points of the surveyed plots (T8, T9, T10) by height categories

Height category	T8		T9		T10	
	Height category	Number of elements (n)	Height category	Number of elements (n)	Height category	Number of elements (n)
102.0-102.5 m	3		97-97.5 m	8	90.0-91.0 m	3
103.0-103.5 m	4		97.5-98 m	6	91.0-91.5 m	10
103.5-104.0 m	6		98-98.5 m	7	91.5-92.0 m	3
104.0-104.5 m	6		-	-	-	-

In defining the height categories, I took into account the location of the sampling points on the given plot, so that the areas represented by each point, i.e., the set of height categories defined by a set of points of nearly the same height (within 0.5 m), covered

almost the whole plot. On the other hand, I also took into account that each height category contained a statistically valuable number of elements.

### ***Estimation of the soil mass moved***

Based on the elevation data from the sampling points, I estimated the amount of soil removed from the higher elevation areas of the three plots and placed on the lower elevation areas. The percentages shown on the elevation maps were used to determine the size of the area of each elevation category: the size of the plot (e.g., 23.3 ha for plot T8) was multiplied by the percentage of each area (e.g., 103.3-103.6 m 16%). I then calculated the difference in elevation (m) between the sampling points of each study plot before and after scraping, averaging the values within each elevation category.

The product of the average height difference (m) and the area of the given area (m<sup>2</sup>) is the amount of soil removed (negative value) or added (positive value) in cubic metres. The volume of earth moved (m<sup>3</sup>) was multiplied by the volume mass of the soil in the area (t m<sup>-3</sup>) to estimate the mass of earth moved. Of course, these are only estimates, as the sampling points did not cover the whole area and I could not account for soil compaction during the 1 year between the test dates. Nevertheless, these soil mass estimates provided a useful basis for calculating the amount of material (e.g., macro- and meso-elements) in the soil that was moved.

### ***Test methods for soil samples***

The laboratory testing of the soil samples was carried out in the "Felső-Bácskai Agrolabor" (URL 2024a) , in the testing laboratory of Agrokémiai Szolgáltató Kft. accredited under NAH-1-1125/2019. The names and methods of the laboratory tests are given in *Table 2*.

*Table 2.* Names and methods of the laboratory tests carried out

<b>Testing</b>	<b>Full (official) name of the test</b>	<b>Method (standard) name</b>
Plasticity ( $K_A$ )	Plasticity index by Arany	MSZ-08-0205:1978 Clause 5.1
Total salt	Total water-soluble salts	MSZ-08-0206-2:1978 Clause 2.4
pH value ( $pH_{(KCl)}$ )	pH (KCl suspension)	MSZ-08-0206-2:1978 Clause 2.1
Lime ( $CaCO_3$ )	Calcium-carbonate content	MSZ-08-0206-2:1978 Clause 2.2
Humus (Hum)	Humus content (Organic carbon content)	MSZ-08-0210:1977 Clause 2.1
Phosphorus ( $P_2O_5$ )	Phosphorus content (expressed as phosphorus pentoxide ( $P_2O_5$ )) (AL soluble)	MSZ 20135:1999 Clause 5.4.2
Potassium ( $K_2O$ )	Potassium content (expressed as potassium oxide ( $K_2O$ )) (AL soluble)	MSZ 20135:1999 Clause 5.3
Sodium (Na)	Sodium content (AL soluble)	MSZ 20135:1999 Clause 5.3
Magnesium (Mg)	Magnesium content (KCl soluble)	MSZ 20135:1999 Clause 5.2
Sulphate of sulphur ( $SO_4-S$ )	Sulphated sulphur content (KCl-soluble)	MSZ 20135:1999 Clause 5.4.1

### ***Determination of soil resistivity by penetrometer***

Soil compaction can also be characterised by measuring bulk density and soil resistivity, but the latter is a faster and more cost-effective method. Soil resistivity is measured using a penetrometer, which determines the compressive and shear strength of the soil and records the strength of the different layers. (Takács, 1990) The instruments commonly used in Hungary to measure penetration resistance, which varies according to soil type, include the Dvoracsek penetrometer (Dvoracsek, 1968), the Penetronik from Sarva (Daróczi and Lelkes, 1999; Penetronik, 2024), and the 3T SYSTEM layer indicator (Sinóros-Szabó and Szöllősi, 1999). The values are given in  $N/cm^2$  or MPa.

Soil resistivity is a measure of soil compaction and depends on the moisture content, bulk density, and physical parameters of the soil. It is necessary to measure soil resistivity at the same time as moisture content because dry or compacted soil can show extreme values (Campbell et al., 1991; Rátónyi, 1999). Knowledge of moisture content is essential for assessing the effects of agrotechnical interventions (Kocsis et al., 1992).

The penetrometer can be used to determine soil compactness, looseness, depth, and thickness of the compacted layer, allowing spatial and temporal analysis of the physical

state of the soil (Koolen and Kuipers, 2012). The method is fast, can be performed in a large number of replicates and provides accurate data for the choice of cultivation time and method. The instruments are often supplemented with a moisture meter to aid interpretation of the results.

The use of this method is limited in gravel, stony soils where the movement of the probe is hampered. In heavily compacted soils, the penetrating probe cone may cause cracks and results may be inaccurate (Freitag, 1971).

### ***Data processing and evaluation methods***

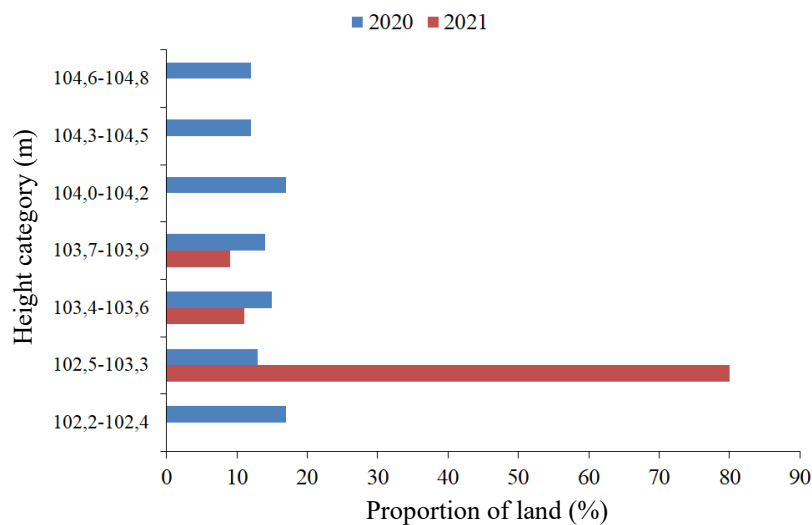
In addition to topographic maps, the research data were processed using both descriptive and complex statistical calculations. In order to facilitate data organisation and processing, the three crop plots (T8, T9 and T10) were classified into three altitude categories. The analyses are plotted and presented according to the altitude categories. Descriptive statistical methods used in the analyses are the mean and the summary, while the composite statistical methods used for the comparative analysis of individual soil parameters are the one-factor analysis of variance and the paired t-test.

### 3. NEW CONTRIBUTIONS TO ACADEMIC KNOWLEDGE

Due to extent limitations, the results of the examinations gained from one plot (T) are summarized in this thesis booklet, nevertheless, the main trends described here are valid for the other two plots under study.

#### Effect of scraping on the topography of plot T8

The first sampling on plot T8 took place in 2020 and then, following the land mass allocation, the sampling was repeated in 2021 on the same 19 points. The average elevation of the plot before the land mass movement was 97.8 m, with a maximum difference in elevation of 0.5 m. After the scraping, the topography of the plot became more homogeneous, with the proportion of the lowest and highest elevations decreasing to 0% and the proportion of the intermediate elevations (102.5-103.3 m) increasing from 13 to 80% (*Figure 2*). After the intervention, the plot, which initially had a very heterogeneous topography, was divided into three parts, each of which could be considered homogeneous, which is in line with the objective of the scraping.



*Figure 2.* Change in the percentage of different heights due to scraping (2020-2021)

Based on the elevation data from the sampling points, I estimated the amount of soil removed from the higher elevation parts of plot T8 and the amount of soil placed on the lower elevation parts (*Table 3*).

Table 3. Volume and mass of land moved on the area of plot T8 (2020)

Height category (m)	Size of the area (ha)	Average change in altitude (m)	Moved soil volume (m <sup>3</sup> )	Moved soil mass (t)
102.2-102.4	3.96	0.95	+37.630	+52.681
102.5-103.3	3.03	0.34	+10.299	+14.418
103.4-103.6	3.50	0.16	+5.592	+7.829
103.7-103.9	3.26	-0.04	-1.305	-1.827
104.0-104.2	3.96	-0.40	-15.844	-22.182
104.3-104.5	2.80	-0.40	-11.184	-15.658
104.6-104.8	2.80	-0.90	-25.187	-35.262
Total	23.3		53.520	74.928

The data in the table clearly show that the estimated 53,520 m<sup>3</sup> of soil removed from 12.3 ha of higher ground (103.7-104.8 m) was distributed over 10 ha of lower ground (102.2-103.9 m).

### Effect of scraping on the pH value

The pH values of the samples taken from the 0-30 cm soil layer at 19 points of the T8 test plot are presented in 4 height categories (*Figure 3*).

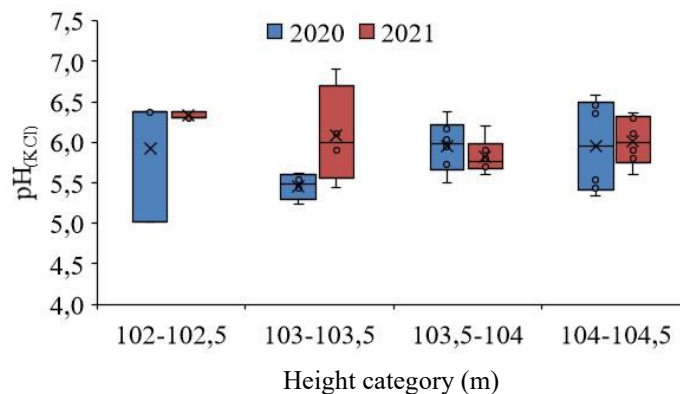


Figure 3: Soil pH<sub>(KCL)</sub> values before and after scraping (n=3, 4, 6, 6)

Regarding the pH test results, it can be observed that the pH ranged from 5.0 to about 6.4 pH at 102-102.5 m a.s.l., which increased after scraping and showed a much smaller variance. For the 103 to 103.5 m a.s.l. category, the original pH value of between 5.3 and 5.6 showed a clear increase after scraping, with the lowest value corresponding to the highest of the original. For the two higher elevation categories (103.5-104 m and 104-104.5 m), there was little or no change in soil chemistry on average, although there was a slight decrease in the standard deviation.

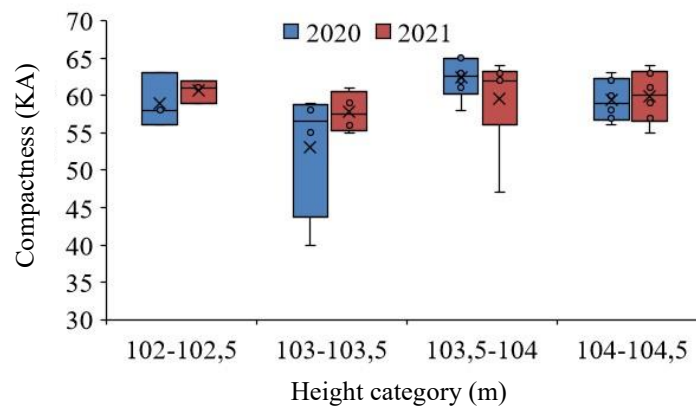
The results of the paired t-test (*Table 4*) show that statistical differences can be detected for all four altitude categories, as soil chemistry (pH) increased in all altitude categories as a result of scraping, i.e. soil acidity decreased. The lower altitude areas (102-102.5 and 103-103.5 m) show a greater increase in chemistry than the higher altitude areas (103.5-104 and 104-104.5 m).

*Table 4.* Results of the paired t-test for soil pH values before and after scraping by height categories

Height category (m)	102-102.5		103-103.5		103.5-104		104-104.5	
	2020	2021	2020	2021	2020	2021	2020	2021
Average	5.923	6.326	5.460	6.085	5,967	5,820	5,952	6,010
Variance	0.612	0.002	0.027	0.371	0,099	0,045	0,327	0,088
Item number	3	3	4	4	6	6	6	6
t Stat	-0.919		-1.719		1.169		-0.404	
P(T<=t) two-tail	0.455		0.184		0.295		<b>0.702</b>	
t Critical two-tail	4.302		3.182		2.570		2.570	

### Effect of scraping on soil plasticity

In the case of plot T8, the sample points were grouped into 4 categories when testing for plasticity. Category 1 is 102-102.5 m, 2 is 103-103.5 m, 3 is 103.5-104 m and 4 is 104-104.5 m. The number of sample points in each category is 3, 4, 6, 6 (*Figure 4*).



*Figure 4.* Soil plasticity values ( $K_A$ ) of the soil before and after scraping ( $n=3, 4, 6, 6$ )

For the 2020 results, it can be observed that the 102-102.5 m above sea level category had a larger variance than the post-land mass allocation sampling. The same characteristics were also observed for the 103-103.5 m altitude, but not only did the variance decrease after scraping, but also the compactness increased (up to 60  $K_A$ ). For

the 103.5-104 m altitude category, the compactness decreased after scraping, and the compactness decreased from 65-60 K<sub>A</sub> to 56-60 K<sub>A</sub> at the sampling points.

According to the results of the paired t-test (*Table 6*), a significant difference was found for the two lowest-lying areas for the plasticity index by Arany (102-102.5 and 103-103.5), while the difference was not statistically confirmed for the highest-lying areas.

*Table 6.* Results of the paired t-test for the plasticity index by Arany before and after scraping by height categories

Height category (m)	102-102.5		103-103.5		103.5-104		104-104.5	
	2020	2021	2020	2021	2020	2021	2020	2021
Average	59.00	60.67	53.00	57.75	61,83	58,17	59,33	59,83
Variance	13	2.33	78	7.58	642,45	627,21	7,87	12,17
Item number	3	3	4	4	5	5	6	6
t Stat	-0.945		-1.133		2.001		-0.344	
P(T<=t) two-tail	0.444		0.339		0.102		<b>0.745</b>	
t Critical two-tail	4.302		3.182		2.570		2.570	

### ***Evaluation of the change in soil plasticity***

The results of the one-factor analysis of variance (*Table 7*) shows that for the highest elevation T8 plot, the average plasticity index by Arany increased by about 0.899% (from 58.89 to 59.42) after scraping, which can be considered as a negligible increase, but the increase in tilth can be considered as negative for crop production, while the significantly decreasing variance shows a more even distribution within the plot, which is the basic objective of land mass allocation. A p-value greater than 0.05 indicates that there is no statistically significant difference in the value of the bound between the years of the study. A low F-value (0.7407) indicates that the variability between group averages is not significantly greater than within each group.

*Table 7.* Results of the one-factor analysis of variance for the soil plasticity values (K<sub>A</sub>) of the entire T8 plot before and after scraping

<i>Groups</i>	<i>Item number</i>	<i>Total</i>	<i>Average</i>	<i>Variance</i>			
2020	19	1119	58.89	30.32			
2021	19	1129	59.42	17.03			
<i>Factors</i>	<i>SS</i>	<i>df</i>	<i>MS</i>	<i>F</i>	<i>p-value</i>	<i>F crit.</i>	
Between groups	2.631	1	2.631	0.1113	0.7407	4.1131	
Within the group	852.42	36	23.67				
Total	855.05	37					

### Effect of scraping on the total dissolved salt content

Total dissolved salinity sampling for plot T8 was first carried out in 2020 and then repeated in 2021 after the land mass allocation, using the same sampling points and under the same conditions. The results are summarised in Figure 5.

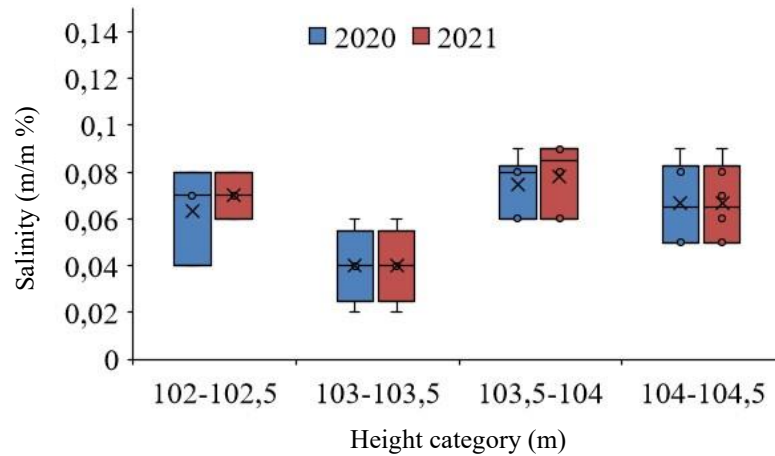


Figure 5. Total water-soluble salt content of the soil before and after scraping

For total water-soluble salinity, there was less noticeable change after scraping, with the exception of the 102-102.5 m altitude category. In this case, the initial water-soluble salinity ranged from 0.04 m/m% to 0.08 m/m% at the sampling points, with a smaller variation after soil mass distribution (0.06 m/m%-0.08 m/m%). There was no change in total water-soluble salinity for the 103-103.5 m elevation category after scraping, which was followed by the 104-104.5 m elevation category. The 103.5-104 m altitude category still showed a difference, with total water-soluble salinity ranging from 0.06-0.085 m/m% before the land mass allocation (2020 sampling), while after the scraping the upper limit of this value was extended and showed values ranging from 0.06-0.09 m/m%.

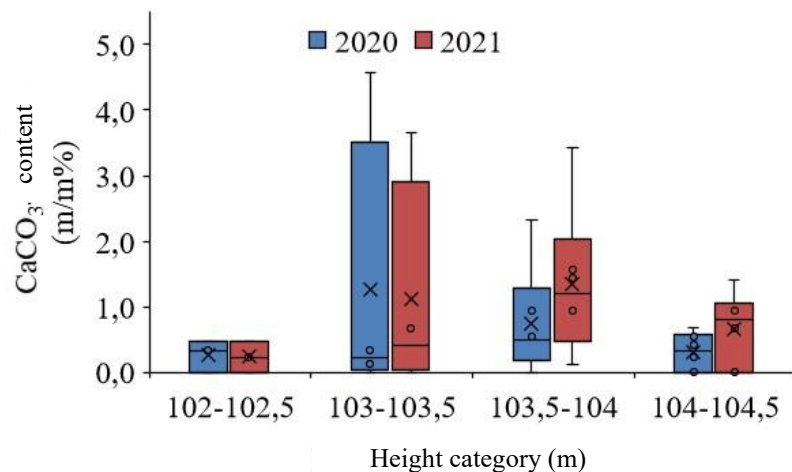
The results of the paired t-test demonstrate that the total dissolved salinity of the tested plots before and after scraping does not show any significant change, i.e. no significant difference in total dissolved salinity can be detected as a result of scraping (Table 8).

*Table 8.* Results of the paired t-test for the total dissolved salt content of the soil before and after scraping by height categories

Height category (m)	102-102.5		103-103.5		103.5-104		104-104.5	
	2020	2021	2020	2021	2020	2021	2020	2021
Average	0.06	0.07	0.047	0.047	0,074	0,078	0,064	0,064
Variance	0.0008	0.0002	0.0001	0.0001	0,0002	0,0003	0,0004	0,0003
Item number	3	3	4	4	6	6	6	6
t Stat	-1		0		-1.580		0	
P(T<=t) two-tail	0.423		0		0.175		<b>1</b>	
t Critical two-tail	4.302		0		2.570		2.570	

### Effect of scraping on soil calcium-carbonate content

For plot T8, the calcium-carbonate analysis was first carried out in 2020, prior to the intervention, and then repeated after the land mass allocation (2021). The results can be seen in *Figure 6*.



*Figure 6.* Calcium-carbonate content of the soil before and after scraping

For the 102-102.5 m altitude category, it was observed that there was no significant change in the calcium-carbonate content after scraping, so the results also showed a maximum  $\text{CaCO}_3$  content of 0.5 m/m%. For the 103-103.5 m altitude category, the values ranged up to 3.5 m/m% before soil mass distribution, with a decrease after scraping. At that time, the samples showed a maximum  $\text{CaCO}_3$  content of only 2.9 m/m%. Furthermore, it can be observed from Figure 18 that the highest detectable calcium-carbonate content is found in T8, but the variance is also the highest here. At the altitude category 103.5-104 m (*Figure 6*), it can be seen that the calcium-carbonate content ranged

from 0.2 m/m% to 1.3 m/m%, which after scraping showed the lime content values ranging from 0.5 m/m% to 2.1 m/m%.

Based on the results of the paired t-test, it can be observed that the calcium-carbonate content of the T8 table soil after scraping shows a slight decrease in the area of the lowest elevation category, the area of 103-103.5 m has no change in calcium-carbonate content, while the two higher elevation areas (103.5-104 and 104-104.5) show an increase in calcium-carbonate content of 118.22% and 122.96%, respectively (*Table 9*).

*Table 9.* Results of the paired t-test for the calcium-carbonate content of the soil before and after scraping by height categories

Height category (m)	102-102.5		103-103.5		103.5-104		104-104.5	
	2020	2021	2020	2021	2020	2021	2020	2021
Average	0.24	0.115	1.633	1.633	0.428	0.934	0.27	0.602
Variance	0.115 2	0.0264	6.495	4.277	0.1242	0.356	0.0873	0.3701
Item number	2	2	3	3	5	5	5	5
t Stat	1		2		-2.28		-2.33	
P(T<=t) two-tail	0.5		0.3178		0.085		0.080	
t Critical two-tail	12.70		4.30		2.776		2.776	

### **Effect of scraping on soil humus content**

The humus content values of the samples taken from the 0-30 cm soil layer at 19 points of the T8 test table are presented in 4 height categories (*Figure 7*). Obviously, our hypothesis was that the humus-rich topsoil from the higher parts of the site was moved to the deeper areas.

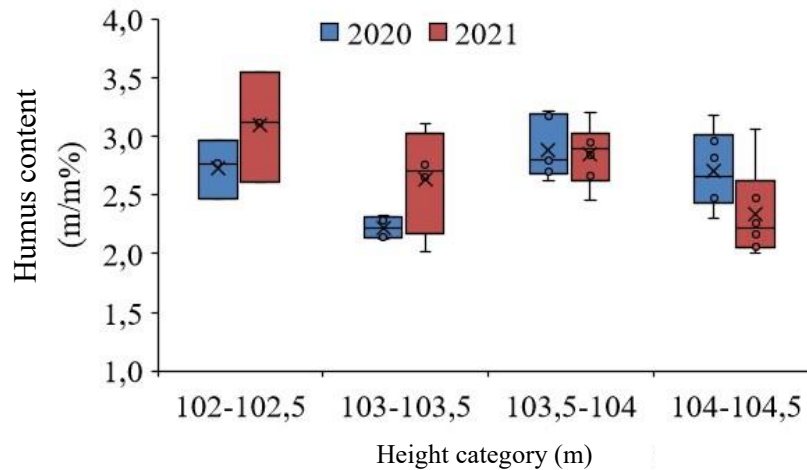


Figure 7. Humus content of the soil before and after scraping

It can be observed that the average humus content has increased (from 2.73% to 3.09% and from 2.22% to 2.64%, respectively). The humus content in the two areas originally deeper (102-202.5 and 103-103.5 m) and in the soil of the higher sampling sites (103.5-104 m) has slightly decreased (from 2.89% to 2.85%).

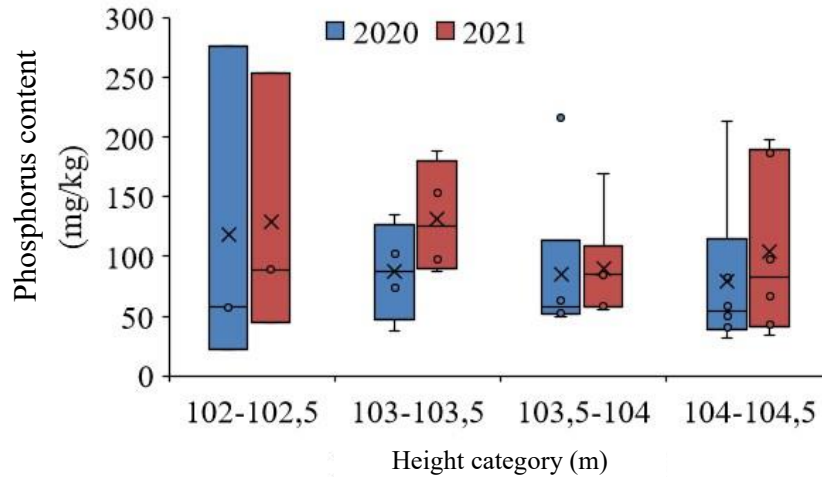
The results of the two-sample paired t-test analysis of the data are summarised in Table 10, which shows that the differences in the two initially deeper areas are not statistically justified, in contrast to the highest area (104-104.5 m), where the humus content decreased significantly (from 2.7% to 2.34%,  $LSD_{5\%} = 0.266\%$ ).

Table 10. Results of the paired t-test for soil pH values before and after scraping by height categories

Height category (m)	102-102.5		103-103.5		103.5-104		104-104.5	
	2020	2021	2020	2021	2020	2021	2020	2021
Average	2.73	3.09	2.22	2.64	2.89	2.85	2.70	2.34
Variance	0.065	0.221	0.010	0.207	0.062	0.067	0.111	0.152
Item number	3	3	4	4	6	6	6	6
t Stat	-2.855		-1.804		0.366		2.783	
P(T<=t) two-tail	0.104		0.169		0.729		<b>0.039</b>	
t Critical two-tail	4.303		3.182		2.571		2.571	

### Effect of scraping on soil phosphorus content

The first sampling of plot T8, similar to the previous ones, took place in 2020, and then the land mass allocation within the plot was done. A further sampling and analysis was carried out in 2021, the results of which are shown in Figure 8.



*Figure 8.* Phosphorus content ( $P_2O_5$ ) of the soil before and after scraping

As can be seen in *Figure 8*, the phosphorus content varied considerably after scraping, so I analysed each category separately. For the 102-102.5 m elevation category, phosphorus values ranged from 20 mg/kg to 275 mg/kg before the intervention, while after the scraping the lowest value increased (45 mg/kg), but the highest value decreased (255 mg/kg). For the 103-103.5 m elevation category, an increase was observed after the scraping, as the lowest value detected before was 45 mg/kg and the highest value was 125 mg/kg phosphorus. After scraping, the lowest detected value increased to 90 mg/kg, while the highest value was found to be 180 mg/kg phosphorus. For the 103.5-104 m height category, a slight decrease in variance was observed after the intervention, but for the 104-104.5 m height category, an increase was observed in both variance and phosphorus content. Prior to the intervention, the lowest value was 40 mg/kg phosphorus, while the highest value was 90 mg/kg, but after the land mass allocation, there was a slight increase in the lowest value (45 mg/kg), but the highest value increased to 195 mg/kg phosphorus.

The results of the two-sample paired t-test analysis of the data are summarised in *Table 11*, which shows that there is a statistically significant difference in all four height categories after scraping. The variance of soil phosphorus content in the two lower elevation areas shows an increase, while the variance in the two higher elevation areas shows a decrease, however, all four elevation categories show an increase in soil phosphorus content, which can be considered as positive for crop production.

Table 11. Results of the paired t-test for the phosphorus content of the soil before and after scraping by height categories

Height category (m)	102-102.5		103-103.5		103.5-104		104-104.5	
	2020	2021	2020	2021	2020	2021	2020	2021
Average	39.75	67	103.63	143.33	87.12	91.4	78.84	88
Variance	616.005	968	925.92	2686.33	5265.10	2110.8	5764.99	4395.5
Item number	2	2	3	3	5	5	5	5
t Stat	-0.6890		-2.97		-0.2756		-0.8949	
P(T<=t) two-tail	0.6159		0.0971		0.7964		<b>0.4213</b>	
t Critical two-tail	12.706		4.302		2.7764		2.776	

### Effect of scraping on soil potassium content

Figure 9 shows the change in potassium content after the tests in 2020 and 2021.

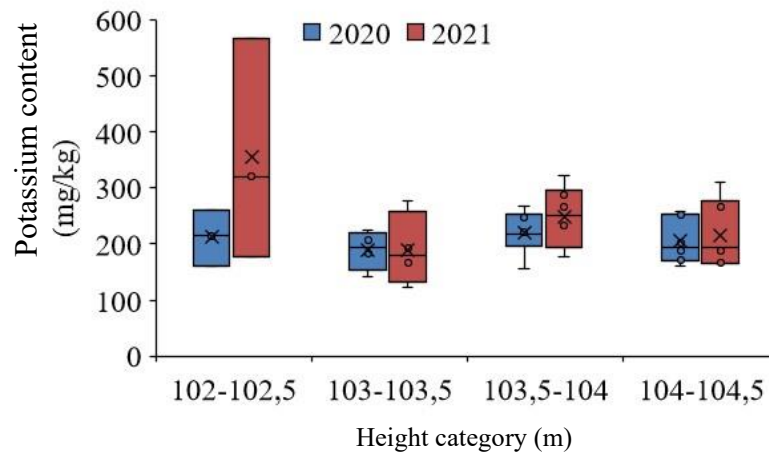


Figure 9. Potassium content ( $K_2O$ ) of the soil before and after scraping

Based on the tests carried out in 2020, for the 102-102.5 m altitude category, it can be seen that the lowest measured potassium content is 150 mg/kg, while the highest is 250 mg/kg. After scraping, an increase was observed for the lowest value (160 mg/kg), while the highest measured potassium content was 570 mg/kg. For the 103-103.5 m altitude category, there was also an increase in potassium after scraping, but the same was true for the 103.5-104 m altitude category and the 104-104.5 m altitude category. Furthermore, it can be seen from the figure that, in addition to the increase in potassium content, there was also an increase in variance after soil mass distribution.

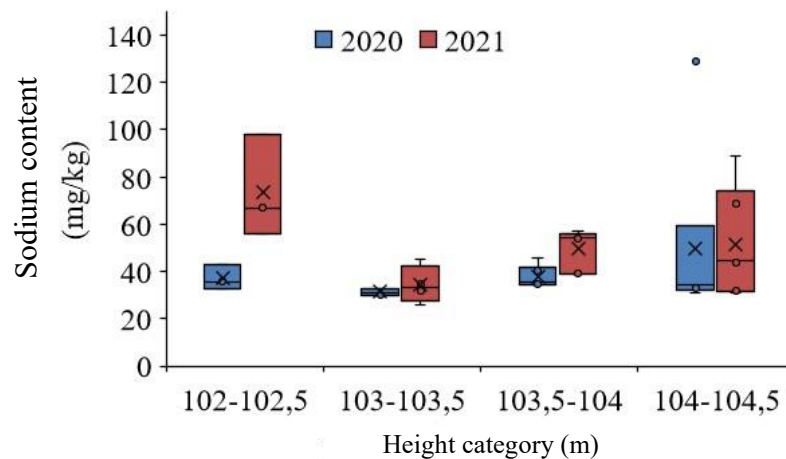
The results of the two-sample paired t-test are shown in *Table 12*, which shows an increase in mean potassium content for all height categories after scraping, as well as an increase in the variance of the data. The increase in the average potassium content can be considered positive for crop production.

*Table 12.* Results of the paired t-test for the potassium content of the soil T8 before and after scraping by height categories

Height category (m)	102-102.5		103-103.5		103.5-104		104-104.5	
	2020	2021	2020	2021	2020	2021	2020	2021
Average	188.05	372.5	204.63	213	220.42	244.2	196.5	206
Variance	1485.1	75660	406.62	3351	1818.8	3670	1451.8	3645
Item number	2	2	3	3	5	5	5	5
t Stat	-1.102		-		-1.106		-0.5646	
P(T<=t) two-tail	0.4688		0.3646		0.3666		0.6024	
t Critical two-tail	12.70		4.302		2.776		2.776	

### Effect of scraping on soil sodium content

Sodium was tested in 2020 prior to the scrapie intervention and repeated in 2021 after the intervention. The results of the sample analysis are summarised in *Figure 10*.



*Figure 10.* Sodium content of the soil before and after scraping

Sodium also showed an increase in all four height categories. The lowest value for the 102-102.5 m altitude category was 30 mg/kg, while the highest value was 42 mg/kg. After land mass allocation, the lowest sodium content was 55 mg/kg, while the highest was

close to 100 mg/kg. However, not only was there an increase in the value scales, but the variance was also confirmed, which can be seen in Figure 30. For the area in the 103-103.5 m altitude category, it can be observed that the average sodium content increased from 37.07 mg/kg to 73.67 mg/kg. After scraping, the variance of soil sodium data increased by a factor of 18. The lowest potassium value before soil mass distribution was 33 mg/kg, while the minimum sodium value after scraping was 56 mg/kg. The average sodium content of the soil at 103.5-104 m elevation increased from 37.68 mg/kg before scraping to 50 mg/kg, an increase of about 32.69%. The change in the higher area (104-104.5 m) is completely different from the areas in the previous three altitude categories, as the lowest value of the average sodium content before and after the scraping does not show any significant change (from 49.63 mg/kg to 501.67 mg/kg).

According to the results of the paired t-test (*Table 13*), the average sodium content of the soil increased after scraping for all altitude categories, with the highest increase in the 102-102.5 m altitude range. The variability of the data shows a significant increase in the lower areas, but a large decrease in the highest area (104-104.5 m).

*Table 13.* Results of the paired t-test for the sodium content of the soil before and after scraping by height categories

Height category (m)	102-102.5		103-103.5		103.5-104		104-104.5	
	2020	2021	2020	2021	2020	2021	2020	2021
Average	37.07	73.67	31.4	34.5	37.68	50	49.63	51.67
Variance	25.90	474.33	1.86	63	21.87	73.6	1503.7	522.27
Item number	3	3	4	4	6	6	6	6
t Stat	-2.551		-0.8792		-3.186		-0.1959	
P(T<=t) two-tail	0.125		0.4440		0.0243		0.8523	
t Critical two-tail	4.302		3.182		2.570		2.570	

### **Effect of scraping on soil magnesium content**

For magnesium, as before, the first test was carried out in 2020 and then repeated at the same sampling points in 2021 after the scrapers were tested. The results can be seen in *Figure 11*.

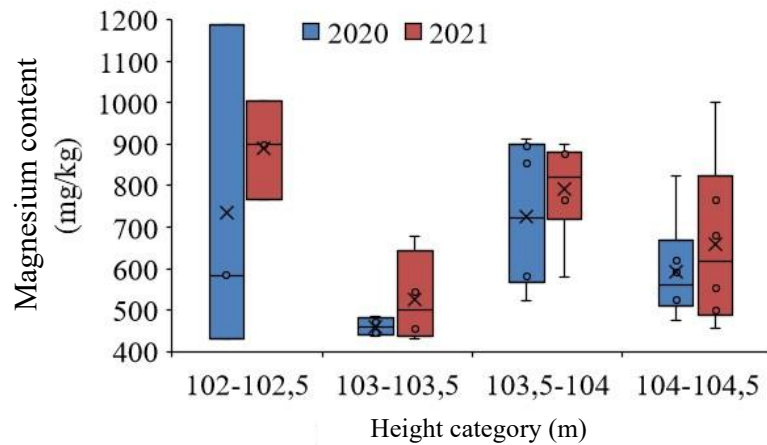


Figure 11. Magnesium content of the soil before and after scraping

For magnesium, the results were quite different in the height categories, so I have covered each category separately. For the 102-102.5 m altitude category, there was a wide variation in the results prior to scraping, with the lowest value being 420 mg/kg magnesium and the highest value being 1200 mg/kg magnesium. After land mass allocation, the variance decreased and an increase was observed in the lowest value, but a decrease in the highest value. Accordingly, the scale concerned was modified as follows: values between 760 mg/kg magnesium content and 1000 mg/kg magnesium content were measured. For the altitude category 103-103.5 m, it was observed that the values in the 2020 sampling showed a lowest magnesium content of 420 mg/kg, while the highest value was around 490 mg/kg. However, an increase in the variance was observed following the stratification, resulting in an increase in the highest magnesium content (650 mg/kg). A reduced variance was observed for the 103.5-104 m altitude category, resulting in an increase in the lowest magnesium content (570 mg/kg) for the 2020 sampling (710 mg/kg) and a decrease in the highest value (900 mg/kg) to 890 mg/kg magnesium content for the 2021 sampling.

The results of the paired t-test (*Table 14*) show that the average soil magnesium content increased in all height categories, but the increase was not equal. The increase in soil magnesium content was 21.18% for the 102-102.5 m elevation category and 14.69% for the 103-103.5 m elevation category, while the increase in soil magnesium content was only 9.24% for the 103.5-104 m elevation category and 11.05% for the 104-104.5 m elevation category after scraping.

Table 14. Results of the paired t-test for the magnesium content of the soil before and after scraping by height categories

Height category (m)	102-102.5		103-103.5		103.5-104		104-104.5	
	2020	2021	2020	2021	2020	2021	2020	2021
Average	734.17	889.67	459.72	527.25	726.07	793.17	593.12	658.67
Variance	160196	14465	518.30	12374	31737	14561	15308	41437
Item number	3	3	4	4	6	6	6	6
t Stat	-		-1.169		-0.649		-0.7737	
P(T<=t) two-tail	0.6237		0.3454		0.544		0.4740	
t Critical two-tail	4.302		3.182		2.570		2.570	

### Effect of scraping on soil sulphur content

The soil sulphur content of plot T8 was first analysed in 2020 and then in 2021 after the land mass allocation. The results obtained during the sampling are illustrated in Figure 12.

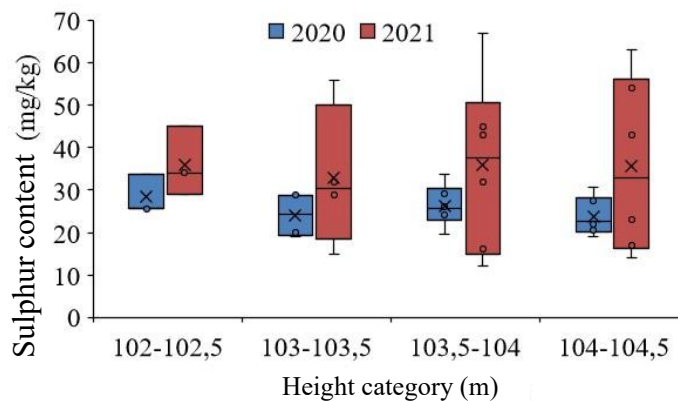


Figure 12. Sulphur content ( $SO_4^{2-}$ ) of the soil before and after scraping

The sulphur content of the soil in plot T8 was between 26 and 34 mg/kg before soil mass distribution and between 29 and 45 mg/kg after scraping. This means that both the sulphur content of the 102,102,5 m height category area and its dispersion increased as a result of the scraping. The sulphur content of the area in the 103-103.5 m altitude category ranged from 19-29 mg/kg, with a wider range (15-56 mg/kg) after scraping. The variance of the data shows a significant increase (27.07%). For the area in the 103.5-104 m altitude category, the sulphur content of the soil before scraping ranged from 20 to 34 mg/kg, and after soil mass distribution from 12 to 67 mg/kg. Consequently, the distribution of sulphur content increased significantly after scraping. As for the highest altitude soils, as in the three previous altitude categories, the variance of the sulphur content data shows a

significant increase, which is about 21 times higher for the area in the altitude category 104-104.5 m.

The results of the paired t-test (*Table 15*) show that the sulphur content of the soil increased after scraping for all four height categories, which is also true for the distribution of sulphur in the soil, as the distribution of sulphur content showed an increase for the soils of all four height categories.

*Table 15.* Results of the paired t-test for the sulphur content of the soil before and after scraping by height categories

Height category (m)	102-102.5		103-103.5		103.5-104		104-104.5	
	2020	2021	2020	2021	2020	2021	2020	2021
Average	28.33	36	24.12	32.95	26.27	35.83	23.8	35.66
Variance	22.41	67	29.34	290.54	22.89	416.56	19.84	423.06
Item number	3	3	4	4	6	6	6	6
t Stat	-1.095		-0.8172		-1.267		-1.478	
P(T<=t) two-tail	0.387		0.4736		0.2607		0.1992	
t Critical two-tail	4		4		4		4	
t Critical two-tail	4.302		3.182		2.570		2.570	

### **Effect of scraping on the penetration resistance of soil**

The results of the penetration resistance tests of the top 60 cm soil layer of plot T8 show that the scraping decreased the penetration resistance in the upper soil layers (0-13 cm, 0-30 cm, 0-20 cm, 0-21 cm), while it increased in the deeper layers. The tests showed that the critical point at which the effect of the intervention is levelled off and the direction of change reversed is found at an average depth of 22 cm. The looseness of the topsoil layer improved in a statistically proven way: the penetration resistance decreased by an average of 0.26 MPa after the intervention (LSD5% = 0.11 MPa). The scraping therefore had a positive effect on the topsoil layer.

#### 4. NEW SCIENTIFIC RESULTS

1. I have found that scrapers can be used successfully for both the meliorative and reclamation treatment of inland water- and air-impacted soils. I have quantified the effects of this technique on the physical and chemical properties of a lowland bound meadow soil and the yield of the crop grown on it.
2. Statistically verifiable differences attributable to the effect of scraping were found for the following parameters and areas: in the deeper area (T10), pH values decreased by about 7% ( $p=0.034$ ); binding decreased by 5.53%, total dissolved salinity increased by 28.6% ( $p=0.0014$ ); calcium-carbonate content decreased by 45% ( $p=0.0095$ ); phosphorus content increased by 160.2% ( $p=0.0139$ ); magnesium content decreased by 54.34% ( $p=6.55E-12$ ); while sulphur content in the soil of the high altitude area (T8) increased by 38.09% ( $p=0.02$ ).
3. I found that under different topographic conditions, the 70-75 thousand tonnes of soil moved by scraping did not result in humus loss at the table level: the change in humus content was +0.01% and -0.03% on the higher slopes and 5.6% on the lower slopes, but this difference was not statistically significant ( $p=0.335$ ). There was a significant transfer of organic matter from higher to lower areas during soil mass distribution, resulting in a more uniform nutrient supply within the plots.
4. I have shown that the analysis of the different elemental and humus contents of the soil is essential for nutrient supply, since the amount of both essential and trace elements in the soil can be a limiting factor in the development of the crop and the formation of the crop.
5. I have shown that the scraping has increased the overall soil penetration resistance, which is not beneficial for crop production, especially tillage. I have found that there is a critical depth (inflection point) in the studied table where the change in penetration resistance due to scraping is zero, at this depth the direction of the effect of the intervention is reversed. In the study area, the positive, relaxing effect of the scraping was observed up to an average depth of 22 cm. In this layer, the average penetration resistance values were statistically lower by 0.26 MPa before scraping than one year after.
6. I found that in all three study areas, the yields of maize grown in the year after scraping were statistically higher than before scraping ( $p=4.592E-13$ ;  $8.4E-08$ ;  $2.785E-10$ ). The differences were significant for both high and low yields (+1.27-5.06 t/ha), depending

on the vintage effect. Yields were not only higher than in previous years, but also exceeded the county averages. Significant differences in yields between the previously existing altitude categories within the plots were reduced, and the homogeneous topography resulted in homogeneous yields in all three plots studied.

## **5. PRACTICAL UTILIZATION OF THE RESULTS**

In crop production practice, soil mass distribution can be used as a soil improvement technology. Scraping involves the removal of the top layer of soil in higher-lying areas to expose the lower layers, and the movement of soil to lower-lying areas can change the soil structure.

Moving the topsoil to deeper areas essentially results in the existing topsoil being moved deeper, so that a new layer of topsoil is added to the "A" level of the soil.

The main objective of the scraping of the study area was to create a homogeneous, gently sloping topography and thus to drain inland water. Scraping involves moving the soil from one place to another, which means that all the soil components are transported. The most important soil component from a fertility point of view is humus (organic matter). In the area under study, fodder maize is grown to meet the fodder requirements of a large-scale livestock farm. Maize is a soil-demanding crop, so a significant loss of humus through scraping would prevent the soil from maintaining its original fertility. In my research, I quantified the impact of scraping on soil humus and other elemental content by quantifying redistribution.

I have found that scraping is an effective operation to remove harmful water accumulation from the land without loss of humus or nutrient reserves on a plot scale, while the more even distribution of organic matter allows potentially more homogeneous yields, increased security of maize production and self-produced fodder supply.

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## 7. LIST OF PUBLICATIONS IN THE TOPIC OF THE DISSERTATION



**DEBRECENI  
EGYETEM**

**DEBRECENI EGYETEM  
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Nyilvántartási szám: DEENK/14/2025.PL  
Tárgy: PhD Publikációs Lista

Jelölt: Nagy Pál Máté  
Doktori Iskola: Kerpely Kálmán Doktori Iskola  
MTMT azonosító: 10095841

### A PhD értekezés alapjául szolgáló közlemények

#### Magyar nyelvű könyvrészletek (1)

1. Tuba, G., **Nagy, P. M.**, Kovács, G., Sinka, L., Rivera, G. A., Zsembeli, J.: A redukált talajművelési rendszer alkalmazása a Nagykunság kötött talajain.  
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#### Magyar nyelvű tudományos közlemények hazai folyóiratban (3)

2. **Nagy, P. M.**, Tuba, G., Kovács, G., Zsembeli, J.: A szkréperezés hatása a domborzatra és a terméshozamra egy kötött talajú, belvízzel veszélyeztetett területen.  
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IF: 1.3 (2023)

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**A közlő folyóiratok összesített impakt faktora: 1,3**

**A közlő folyóiratok összesített impakt faktora (az értekezés alapjául szolgáló közleményekre):  
1,3**

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Debrecen, 2025.01.17.

