Deterioration of soil quality due to climate change and possible prevention of soil damages

Thesis of doctoral (PhD) dissertation

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Gödöllő

2019

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1. INTRODUCTION

The global climate has never been constant, it had many changes in the history of the Earth. If we are focusing on not only the global scale but on the local conditions also, its more noticeable that the frequency of unusual weather events and the fluctuation of the unusual sudden changes in the local weather are rising. The general soil degradation is one of the outcomes of the extreme weather events due to the erosion cause by heavy rainfalls. Significant losses in the agriculture can be caused by these soil damages, especially in the case of inadequate tillage. The number of relevant studies in this topic is not enough. Finding a possible solution to help farmers to decrease the amount of soil degradation, also to prevent the losses in the agriculture caused by the factors of the climate change is not only interest of the scientific community is also an issue of the national economy. Therefore, the objectives of my research work were:

- Investigation of the effects of tillage treatments in the long-term experiment and measuring the soil condition and crop yields under certain climatic conditions.
- Analysing the interactions between tillage treatments and soil structure, with emphasis on dust and crust formation and earthworm activity.
- Evaluation of the changes in humus content in the 16^{th} year of the long-term experiment, due to the different effects of tillage treatments.
- Proposing solutions that can reduce the impact of climate and farming damages and increase crop safety. Setting up a tillage performance ranking based on the studied parameters.

2. MATERIALS AND METHODS

2.1 Information about the experiment

A long-term tillage experiment was initiated at the Training Farm of the GAK Ltd., nearby the town, Hatvan (47 41’ 31.7” N 19 36’ 36.1” E, 110 m a.s.l), in year 2002 with of a clay-loam texture, Endocalcic Chernozems, Loamic (WRB 2015).

The yearly number of the sunny hours in the area are 1920-1980, the average amount of the precipitation is 520-570 mm/year, the average temperature is 9,5-10,3 °C. The aridity index of the area is 1.20-1.33, the main direction of the wind is NW-SE.

The one-factorial experiment was arranged in a randomised block design (SVÁB 1981) with four replicates. Plot size was 13 m x 185 m. Total area of the trial including edges covers 6.2 hectares. We compared five ploughless tillage treatments with the mouldboard ploughing. The treatments were:

- P: Ploughing (0.28-0.34 m), with surface levelling
- DD: Direct Drilling
- T: Tine tillage (0.22-0.25 m)
- ST: Shallower Tine Tillage (0.18-0.22 m)
- D: Disk Tillage (0.14-0.16 m)
- L: Loosening (0.40-0.45 m), in case of necessity with surface levelling.

The base seasons of the current scientific work were: 2013/2014 (Sunflower), 2014/2015 (Winter wheat) and 2015/2016 (Maize).

2.2 Methods

- **A structure of the soil was examined by** STEFANOVITS (1992), where the soil samples taken from the experiment area, were dried out totally and then they were screened through an agronomic sieve. In this way the soil particles were separated by size. The weights of the fractions are then weighed to determine the ratio of the given aggregate type. The size of the different fractions was: clods (>10 mm), crumbs (10-2.5 mm), small crumbs (2.5-0.25 mm), dust (<0.25 mm).
- **Measurements of the soil moisture content** were made with a Hungarian moisture probe (PT-1 by Kapacitív Kkt.). The probe can measure the moisture content of the soil by electro conductivity till the depth of 0.6 m. We made a measurement in every 5 cm. Beside of the soil moisture data we collected precipitation data as well.
- **Cone Index (Soil penetration resistance) calculated with a help of a penetrometer by the Hungarian** Mobitech Bt. which based on the hand penetrometer of the Ejkelkamp company. We measured the penetration resistance of the soil in every 5 cm of dept until 50 cm, then we calculated the Cone Index in Mega Pascals (MPa).
- **We measured the crust thickness** on the top of the soil in mm, in the same time with the structural measurements.
- **Earthworm activity** was measured with a help of a series of spade tests. In every month we made 5-5 spade tests in every plot, then we counted the number of earthworms found in the soil sample. We converted the number of earthworms per spade test into pcs/sqm.
- **Yield measurements** were made with a help of combines equipped with yield weight measurement system.
- **Humus content** of the plots were measured in every 3 years of the experiment. We took four soil samples of every treatment from a depth of 0–10 cm, 10–20 cm, 20–30 cm and 30–40 cm. The humus content measurements were made at the Soil and Plant Examination Laboratory of the John von Neumann University in Kecskemét.

3. RESULTS

3.1 Results of the dust fraction

The analysis of the dust fraction showed a significant difference between the examined years, but the difference between the treatments is not always statistically significant. In the case of sunflower (in 2014) we found significant difference between the tine tillage and the shallower tine tillage (-3.063%), the loosening (-2.195%) and the direct drilling (-3.474%) treatments, there were no difference between direct drilling (-2.915%) and ploughing.

In the case of the season of winter wheat (2015) the shallower tine tillage treatment was containing less dust with 7.68% compared to ploughing and with 5.59% less than the loosening. There was a significant difference between ploughing and direct drilling, where the ploughing contained 5.44% more dust.

In the season of maize (2016), disk tillage and the direct drilling contained the most dust. The disk tillage showed more than 10% more dust on average than other treatments. Compared to the disk tillage the shallow tine tillage contained less dust with 13.75%, the ploughing with 8.22% and the loosening with 10.86%. In contrast to direct drilling the shallow tine tillage contained less dust with 9.76%, the tine tillage with 9.95%, and loosening with 6.88%. The smallest fluctuations in the 2014 and 2015 seasons were in the tine tillage and the shallow tine tillage treatments, while the highest was in ploughed soil. The slightest fluctuation during the season of maize was also observed in tine tillage, while the dust content in ploughing varied significantly. It can be stated that all the treatments produced dust, but in all three seasons the tine tillage produced the least amount of it.

3.2 Results of the small crumb fraction

Based on the research, ~~the~~ results of the small crumb content in 2014 (sunflower) and 2015 (winter wheat) are not significant. Although, there were no statistical differences between disk tillage and ploughing (25-28%), between shallow tine tillage and tine tillage (40%), and between loosening and direct drilling (35%). These treatments in pair are maintained a similar ratio of the small crumbs. According to the data published by BIRKÁS et al. (2011) and CSORBA et al. (2011) the disk tillage and the ploughing are more likely increasing the amount of dust content than the amount of the ~~small~~ crumb content.

3.3 Results of the crumb fraction

There was no significant difference at the crumb ratio in the case of sunflower (2014) between the shallow tine tillage, the tine tillage, the loosening and the direct drilling. The disk tillage and the ploughing treatments had significantly negatively effect on the crumb ratio. On average, the disk tillage with -7%, the ploughing with -9% contained less crumbs compared to other treatments.

Considering the winter wheat (2015) we found significant differences only in the case of the ploughing compared to the other treatments. The ploughing contained the lowest ratio of crumbs about 25%. In the year 2016 (maize), no significant difference was found between the treatments.

It can be stated that the given tillage treatments in the crumb content showed approximately the same results in all three seasons, only the crumb ratio of the ploughing varied significantly. The disk tillage showed a crumb ratio of about 30% in all seasons, while the tine tillage, the loosening and the direct drilling showed about 30-40% in all three seasons.

3.4 Results of the clod fraction

At the sunflower in 2015 there was no difference between the two tine tillage treatments, nor between the loosening the direct drilling and the ploughing.

In 2016 (winter wheat), there was no statistically significant difference between the disk tillage and ploughing, as well there were no difference between the two tine tillage treatments and between the loosening and direct drilling. In the case of winter wheat (2015), probably due to the dense plantation, we were unable to measure significant differences.

Summarizing the results of the soil structure measurements, it can be concluded that the dusting effect of the ploughing and the disk tillage was confirmed again. Dusting occurred especially in the production of wide row crops. In those treatments where the proportion of small crumbs was higher, the dust content was also more significant (BIRKÁS et al., 2011; CSORBA et al., 2011; FÖLDESI 2013). Based on the results, similarly to BOTTLIK et al. (2014), it can be stated that direct drilling and tine tillage treatments have resulted in a crumbled structure, whereas ploughing and disk tillage ~~treatments~~ have a positive effect on the dust and clod formation.

3.5 Results of the soil moisture content measurements

In the examined seasons, in the 0–15 cm layer the year 2016 differs significantly from 2014 and 2015. The higher soil moisture content measured in 2016 can be attributed to the abundant precipitation (+84 mm) during the season. The statistically significant difference was only between the shallow tine tillage (22.46%) and the direct drilling (25.16%) treatments.

In the case of winter wheat (2015), disk tillage (24.34%) was significantly different from ploughing (20.92%) and tine tillage (21.32%) treatments; however, in the 2016 (season of maize), there was no difference between the treatments

Based on the measurements, there were no significant differences between the examined seasons and nor between the treatments in the 15–30 cm layer as well in the 30–50 cm layer. Treatments are believed to have no long-

term effect on the soil at these depths due to capillary water movements and low evaporation losses.

3.6 Results of the penetration resistance measurements

Examining the depth of 0–15 cm in the case of sunflower (2014), the penetration resistance of the ploughed treatment (1.69 MPa) was significantly lower than that the shallow tine tillage (2.87 MPa), the direct drilling (2.92 MPa) and the disk tillage (3.15 MPa). The difference between disk tillage (3.15 MPa) and tine tillage (1.96 MPa) was also significant.

In 2015 under winter wheat, the penetration resistance of the ploughed soil (2.23 MPa) was the lowest on average at the depth of 0–15 cm, which showed a significant difference compared to disk tillage (4.7 MPa) and a shallow tine tillage (4.1 MPa) and direct drilling (4.5 MPa). The disk tillage treatment (4.7 MPa) was proved to be more compacted in this layer than the tine tillage (2.8 MPa) and loosening (3.1 MPa).

In the season of maize (2016) the ploughed soil was found to have a lower cone index (1.76 MPa) compared to the disk tillage (2.81 MPa) and the shallow tine tillage (2.11 MPa).

At the depth of 15–30 cm, in the 2014 season, a statistically significant difference was found between the ploughed (2.56 MPa), direct drilled (3.92 MPa) and disk tilled (3.79 MPa) treatments. There was no difference between treatments at depths of 30–50 cm in any season.

3.7 Results of crust thickness

When examining the results of the crust thickness, it can be concluded that significant differences were observed between treatments in all three years. In the disk tillage and the ploughing treatments, the crust thickness was about 10 mm higher than in the other treatments. In all three seasons, disk tillage was 4–11 mm thicker than the tine tillage. The same can be observed on ploughed soil, where a difference of 4 to 10 mm has been observed compared to tine tillage. The loosening showed the same results in all three seasons as the direct drilling. On the disk tilled and ploughed soil, the crust thickness was between 14 and 26 mm, while in tine tillage the thickness was between 7 and 14 mm. The smallest seasonal fluctuation was found at shallow tine tillage treatment.

3.8 Results of the earthworm activity measurements

Examination of the number of earthworms has shown that there is a significant difference between treatments. In 2014 ploughing was separated from the other treatments, from the tine tillage with average of -4 pcs/sqm and form the shallow tine tillage with -2pcs/sqm. In 2015 the ploughing was also statistically different from the tine tillage by -8 pcs/sqm and by -6 pcs/sqm from the loosening.

In 2016, under maize, ploughing was different from other treatments by an average of -5 pieces / m^2 than loosening and with -16 pieces / m^2 than direct drilling. The ploughed soil has always resulted in stable low earthworm population. The other treatments showed similar values in relation to each other, and more earthworms in average of + 5-5 pcs/m^2 in relation to ploughing. The greatest fluctuation in the number of earthworms was found in the dry season of 2015. The highest seasonal difference in a season was in the case of the direct drilling which was 80 pieces / m^2 between March and September. In the three seasons of the long-term experiment, ploughing showed the lowest number of earthworms on average (2014: 0.7 pcs/sqm; 2015: 1.8 pcs/sqm; 2016: 2 pcs/sqm), and the highest at the direct drilling (2014: 5.3 pcs/sqm; 2015: 18.7 pcs/sqm; 2016: 18 pcs/sqm). These results of the earthworms are comparable with the results of PEIGNÉ et al. (2009) and PELOSIA et al. (2016).

3.9 Results in yield performance

In 2014, the direct drilling had by 26% less yield and the disking had less yield by 11% compared to the experimental average, which was the highest standard deviation. The second highest SD was in the case of direct drilling, the third in the case of the shallow tine tillage.

In 2015, the yield of disk tillage and direct drilling remained below the experimental average by 12% and 10%. The highest standard deviation was found in shallow tine tillage and tine tillage treatments, which is probably due to the specificity of the field.

In the third season (maize, 2016), the disk tillage was dropped by 6% and the direct drilling yield 4.5% related to the field average.

The most stable and best results were achieved at the tine tillage and the shallow tine tillage treatments on an average of the three years.

3.10 Results of MANOVA

We used Multivariate Analysis of Variance to investigate the combined effects of crops, the tillage and the precipitation. Based on the experimental results, it can be concluded that the tillage, the precipitation and the crop type have no common effect on the yield mainly because of the crops genetic properties. The yield is influenced not only by the cropyear effect (BEKE 2006), the effect of nutrient supply, and the amount of precipitation as stated by MÁRTON (2002), but also by the distribution and the intensity of the precipitation and the genetic properties of the sown crops. It is clear from the data that the tillage treatments and the crop type have the most significant effect on the soil's structure and water regime.

3.11 Results of the Pearson-type correlation

By examination of the correlation between the investigated parameters in 2014, where $r \geq | 0.2 |$ there was a significant correlation between the ratio of the dust ratio, the crumb ratio, and the crop type. There was a negative correlation between soil Cone Index values, which were measured at different depths.

Considering the crumb fraction, there was a significant positive correlation with the number of earthworms. Moreover, there was a negative correlation between the clod ratio and the crust thickness, and also a negative correlation between the crust thickness and the monthly precipitation.

The dust ratio showed a correlation with all the examined factors except for the crumb content and the crop type. The strongest positive correlation with the dust fraction was found in the case of soil moisture content and crust thickness.

In contrast, the crumb ratio showed a positive correlation with the monthly precipitation as with the clod ratio but had a negative correlation with the crust thickness.

In the case of maize in 2016 it can be concluded that the proportion of dust ratio showed a very strong positive correlation with the crust thickness and

a negative correlation with the crumb ratio. The proportion of small crumbs showed a strong correlation with the number of earthworms and a negative correlation with the crust thickness and the clod ratio.

3.12 The results of the Principal Component Analysis

The purpose of the analysis was to group the variables into separate groups, making it easier to interpret the results. The aim was to group the factors influencing the climate sensitivity of the soils. As a result of the study, I was able to distinguish clearly four groups from the thirteen variables. As a result of the study it can be concluded that if we want to characterize the actual soil condition, we have to examine the four main components which are making the soil sensitive to the climate stresses. These components are the soil plasticity, siltation of the soil, degradation of the soil structure and the biota activity.

3.13 Results of the humus content measurements

In average of the four examined seasons (2009, 2011, 2015 and 2018), the humus content has decreased with the change of depth. At a depth of 0 to 10 cm the humus content was between 3.6 to 3.9% at the depth of 30–40 cm the HC decreased to 1.8–2.6%. The sharpest decreasing curve can be observed at the ploughed treatment, which is the effect of the regular inversion of the soil from 0 to 35 cm depth. The steepest diminishing line is observed at the disk tillage and direct drilling, due to their working depth.

Between 2009 and 2011 there was a depression in the humus content of soil in all treatments. For 2015 the humus content at the most treatments reached again the six years earlier values. The highest value was achieved by tine tillage (3.3%) and the lowest by ploughing (2.95%). Disk tillage (3.18%) showed approximately similar results for shallow tine tillage (3.19%), while direct drilling (3.08%) had a similar result like the loosening (3.06%).

In 2018, there was a further slow increase in the humus content except in the case of disk tillage, where a minimal decrease (3.16%) occurred. Two tillage treatments had the highest level (tine tillage: 3.51%; shallow tine tillage: 3.36%), while direct drilling showed the third best result with 3.24%. Based on the results, there is a trend that fluctuates somewhat

between the samples, but overall, there is slowly increasing trend, because since 2002 in all seasons mulching and humus conservation farming has been implemented.

3.15 Ranking of the tillage treatments

Based on the previous results I developed a climate sensitivity ranking of the tillage treatments in Chernozem soils at town Hatvan (Figure 1.).

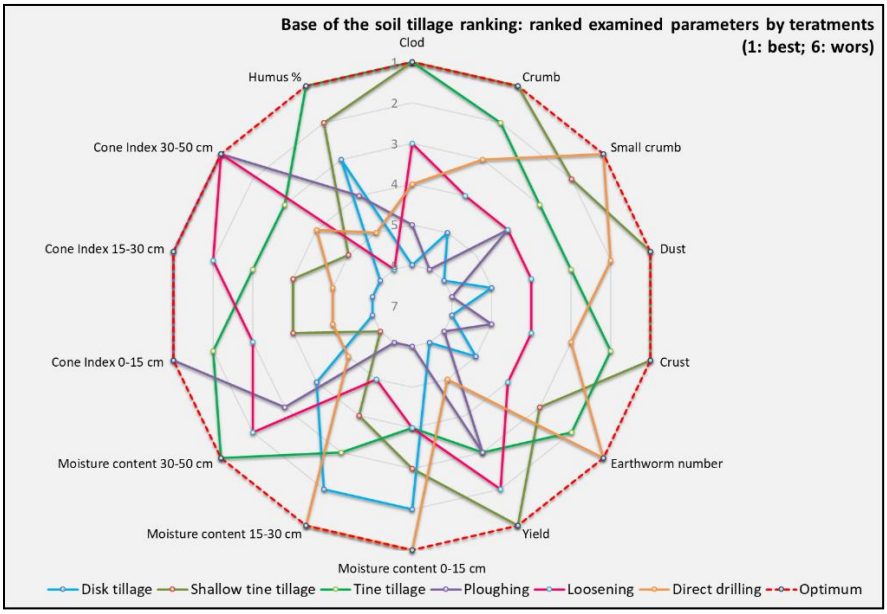

Figure 1. The ranked parameters by tillage treatments

The total rank of treatments (in decreasing order) are: Tine tillage > Shallow tine tillage > Direct drilling > Loosening > Ploughing > Disk tillage. Based on the ranking, the soil is the least sensitive to the effects of climate damage in case of tine tillage and the most sensitive in the case of ploughing and disk tillage. The rankings provide information on which soil tillage method must or may be favoured under similar ecological conditions or in case of volatile and extreme weather conditions.

3.16 New scientific results

1. By examining the combinations of the crops, the tillage and the precipitation, the beneficial effect of the precipitation on the soil structure, as well as the beneficial combined effect of the tillage type and the crops on the soil moisture content and penetration resistance has been proven.

2. The siltation of the soil, the deterioration of the structure and the activity of the soil biota can draw attention to the recognition of climate change phenomena and the knowing of these four factors can help to prevent the climate related damages of the soil.

3. I have detected a close correlation between the surface crust thickness and the soil crumb ratio and the dust ratio of the soil. The role of favourable crumb state is high in the prevention of the surface formation and in the decreasing the influence of crust thickness on the number of earthworms.

4. With the analysis of the soil quality factors I proved the importance of the tine tillage to avoid the negative effects of the extreme climate effects, the negative crop-year effects, as well as its lasting effect on the physical and biological soil characteristics which influencing the yield.

5. An increase in the humus content was proven in a long-term experiment, where humus preservation tillage has been implemented.

6. There was no found any correlation between the soil's Plasticity Index according to Arany (K_A) in different tillage treatments.

7. A new, climate sensitivity ranking of the tillage treatments were developed on Chernozem soils. The rank of treatments (in decreasing order) is: Tine tillage > Shallow tine tillage > Direct drilling > Loosening > Ploughing > Disk tillage. This rank gives information about soil tillage suitability on soils located at similar ecological circumstances and at extreme weather conditions.

4. Discussion

My scientific work was based on a soil tillage long-term experiment in Hatvan, which has been in established in 2002. My scientific work was done between 2013 and 2016. In 2014 nearly average precipitation fell, but in 2015 the average precipitation was below the 100-year average and in 2016 a normal distribution of precipitation was assessed. My main goal was to evaluate the soil conditions affected by the tillage systems and the climate.

The examination of the soil structure confirmed that the lowest amount of dust was produced at tine tillage. The dusting effect of disk tillage and ploughing was repeatedly confirmed, mainly below wide row crops. Regarding the crumb ratio at disk tillage ~ 30% crumb ratio was measured in all seasons, while at the tine tillage, the loosening and direct drilling treatments this ratio was higher about 30-40%. The clod forming was more dominant at direct drilling, which probably caused by the surface disturbance at sowing. These results are similar to the Hungarian literature (BIRKÁS et al., 2011; CSORBA et al., 2011; FÖLDESI 2013).

One of the tillage and climate related damage of the soil is the crust formation, which is related to dust content of the soil. Based on BOTTLIK et al. (2014) on the crust thickness scale, the shallow tine tillage, the tine tillage, the loosening reached the "easy to repair" category in all three seasons, while disk tillage and ploughing can be classified as risky treatments.

The soils biota activity was derived from the number of earthworms. There was a significant difference between tillage treatments. In the average of three years, the lowest number of earthworms was in the ploughed soil 15 pcs/sqm. The highest seasonal variation was measured at the direct drilling with 80 pcs/sqm. According to the measurements, the earthworm rate was the highest in March and April, when the soil habitat was less exposed to the adverse weather effects. These results of the earthworms are comparable with the results of PEIGNÉ et al. (2009) and PELOSIA et al. (2016).

Based on the analysis of the yields the most stable and best results were shown in the case of tine tillage and shallow tine tillage in the average of the three years. This fact reinforces the applicability of the two treatments on the Hatvan region Chernozem soils.

Based on the results in our experiment the crust thickness was affected mainly by the rainfall, its distribution and intensity, but also by the crops, and by the basic tillage method.

There was a correlation between earthworm number and the soil moisture content and there was a negative correlation between the number of earthworms and the crust thickness. There was a negative correlation between the ration of small crumbs, clods and monthly precipitation. However, the crumb ratio showed a positive correlation with the amount of monthly precipitation. There was a negative, but strong correlation between soil penetration resistance and the soil moisture content.

Based on the soil laboratory results, we found that the humus content decreased with the change of depth. A moderate decrease was observed in ploughed soil, probably due to the rotation of the soil layers. The highest change experienced at disk tillage and direct drilling because of their shallow working depth. According to the 2018 results ranking of the treatments are (in decreasing order): Tine tillage (3.5%)> Shallow tine tillage (3.36%)> Direct drilling (3.24%)> Disk tillage (3.18 %)> Loosening (3.17%)> Ploughing (3.01%).

There was no found any correlation between the soil's Plasticity Index according to Arany (K_A) and the tillage treatments, which means that tillage applications do not or slightly change the K_A value.

In total the worst soil quality values were recorded at disk tillage and ploughing, thus these treatments are most sensitive to the climate and to the extreme weather events. The ranking of the tillage treatments according to the results is as follows (in decreasing order): Tine tillage> Shallow tine tillage> Direct drilling> loosening> Ploughing> Disk tillage.

Based on the results, it can be concluded that crop safety, good soil condition and moderate exposure to climate damage can be achieved by

tine tillage in the Hatvan region on Chernozem soils with similar ecological conditions.

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6.1 Publications in international scientific journals

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