SZENT ISTVÁN UNIVERSITY

CREATING THE CONDITIONS OF ADAPTABLE - AND ENVIRONMENT PRESERVING SOIL TILLAGE UNDER FIELD CIRCUMSTANCES

Thesis of PhD dissertation

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1. BACKGROUND AND AIMS OF THE RESEARCH WORK

In the early 1990s 69.6 % of Hungary's 9.3 million hectare territory of was used for agricultural production that dropped to 57.4 % by 2012. Out of the total area used by the agriculture sector the total area of arable lands dropped from 4.7 million to 4.3 million hectares during the same period (CSO 2012).

Due to the ever increasing strive for higher yields and more intensive crop production, tillage operations that respect soil fertility, structure, biological- and chemical condition, have been neglected over the past few decades. Nowadays the sustainable application of land use systems is in focus, since - along with the environment- and soil polluting chemicals that are applied in cropping - the improperly chosen tillage systems may bring on extra expenses, soil degradation and environmental damage.

There are two basic forms of soil tillage (one with, the other without ploughing), of which the soil inversion (ploughing) based tillage is predominant in present Hungary, but tillage systems without ploughing have also been observed to be increasingly widely adopted in recent years. Energy saving production techniques, as well as environmentally friendly technologies have been growing in importance during the past few decades, and the adoption of such techniques entails continuous revision of the production costs (RÁCZ 2009). The introduction of adaptable soil tillage systems - that are carefully adjusted to local site conditions - will be indispensable in the future if sustainable and environment preserving agriculture is aimed on the long run.

Short and long term research experiments are underway across the world to compare the impact of different tillage systems on soil condition and the environment. Significantly smaller amount of literature is, however, available on studies where such tillage systems are examined under field conditions. The findings and results of field experiments can contribute to identifying the impacts of tillage systems on physical soil condition and they can supply a wealth of useful supplementary information for tillage practice.

My research was aimed at achieving the following objectives:

- To study and evaluate the impacts/effects of conventional tillage system on physical soil condition under field circumstances, focusing, in particular, on the agronomic structure of soil, penetration resistance and moisture content which influences the results of crop production.
- To study and evaluate the impact of year effect on the agronomic structure, soil penetration resistance and soil moisture content.

- To assess the profitability of conventional tillage system under specific climate and site conditions, the economic assessment of the applied tillage method.

I studied the impacts of conventional tillage system on physical soil condition under field circumstances. I was seeking the answer to the question that is the subject of the present study: what impacts a conventional tillage system has on the physical soil condition under given site and climate conditions, and whether conventional tillage can be regarded as an economically profitable alternative. In assessing and evaluating the soil condition, I focused on how soil moisture content, soil resistance and soil agronomic structure - each having an impact on the success of cropping - change as a result of conventional tillage over several years.

Weather factors are also worth taking into account for an accurate assessment of physical soil condition. Extreme weather patterns have been growing increasingly frequent in recent years in Hungary too, therefore in the evaluation of soil condition studies the year effect was also taken into account concerning the moisture content, penetration resistance and the agronomic structure. Another objective of this study is to evaluate the conventional tillage system under the given site and climate conditions from an economic perspective.

2. MATERIAL AND METHOD

2.1. The circumstances of the field experiment

2.1.1. Geographical location

The experiments were launched in 2004 in the mid-Hungarian region, in Pest county at six farms between Pánd (N.L. 47°21'01''; E.L. 19°38'00"; altitude above sea level: 129 m) and Káva (N.L. 47°21'19''; E.L. 19°35'16"; altitude above sea level: 131 m). The area is located in a valley surrounded by hills, but the experiments were laid out on a flat area.

2.1.2. Climate conditions

Exact data on the climate conditions prevailing in the site of the experiment were provided by the Climate Department of the Hungarian Meteorology Service for the years concerned. The monthly mean temperature data were measured by an automated meteorological station near the experimental sites. The annual mean temperature averaged over three years was 10.09 °C (with a maximum monthly mean of 21.43 °C in July and a minimum of -1.97 °C in January). The lowest mean annual temperature values (9.81 °C) were recorded in 2005.

Precipitation data were obtained from a recording station in Nagykáta. Out of the three year average of the monthly precipitation means, the highest was recorded in June (71.20 mm) and August (99.43 mm) and the lowest (19.50 mm) in October. The highest annual precipitation (702.1 mm) in the three years was received in 2005. As for the monthly sum of precipitation, it was the highest in August 2005 (137,1 mm).

2.1.3. Soil conditions

The sites of the experiment are located around Káva and Pánd settlements in the Tápió-mente Gödöllő hills region where the dominant soil type on the higher-lying loess-covered hillsides and slopes - heavily structured by erosion-derasion valleys - is a chernozem-brown forest soil of moderate fertility (DUSEK 2007). No soil tests had been carried out on the experiment sites until our field experiments were launched. Therefore between 2004 and 2006 we took average samples after harvest from the top 0-20 cm and the 20-40 cm layers of the soil. For each experiment the mixed soil samples were taken from a homogeneous area by taking soil subsamples of equal mass from several spots along a virtual diagonal in the field concerned. The subsamples were mixed and then taken to the laboratory. The collected soil samples were tested for soil liquid limit, pH, calcium-carbonate content, humus (%) and the available phosphorous and potassium content (*Table 1*).

Table 1: The results of soil analysis in experiments A, B, C, D, E and F (2004-2006)

	K_A	pH_{KCL}	Humusz %	$CaCO_3$ %	$AL\text{-}P_2O_5$ mg/kg	$AL\text{-}K_2O$ mg/kg
A	37	6,74	2,61	5,54	220	161
B	38	7,22	1,26	15,38	66	62
C	38	6,85	2,46	2,73	107	141
D	39	6,66	2,18	2,58	114	139
E	38	6,85	2,46	2,73	107	141
F	38	5,7	2,75	0	230	234

2.1.4. The production technology parameters of the experiments

Conventional soil tillage was applied in each of the field experiments during the period under review (2004-2006). Conventional tillage was usually characterised by higher traffic than would have been reasonable, along with time and energy consuming operations. The depth of tillage had been adapted to the crops' needs and the available tillage equipment. After harvest the crop residues were not used - outside the growing season - to cover the soil surface, to protect the soil and to control soil moisture loss. The aim was always to create a seedbed of fine crumbs, without crop residues. In the field experiments the same tillage systems were applied after harvest in each of the three years: disking of the top soil was followed by autumn ploughing (30 cm). Fertilisers were delivered in the autumn and in the spring, depending on the crop and yield of the previous year. The soil was loosened with cultivators in the spring before sowing. During the three years of the experiment maize and sunflower were grown on the experiment sites. No catch-crops, green manure plants or soil structure improving crops were grown and the soil surface was not covered with crop residues to protect soil and to reduce soil moisture loss. Moreover, no carefully planned crop rotation was applied to improve soil fertility or to increase productivity. The crop sequences in the various experiments are shown in *Table 2*.

Table 2: The crop sequences on the various experiment sites between 2004 and 2006

	2004	2005	2006
A	maize	sunflower	maize
B	maize	sunflower	maize
C	maize	maize	sunflower
D	maize	maize	maize
E	maize	maize	sunflower
F	maize	maize	maize

2.2. Methods and equipment used

2.2.1. Soil moisture content analyses

The soil moisture content was determined twice in 2004 (in June and September) and three times in both 2005 and 2006 (in May, late August and October). To determine soil moisture content, samples were taken at every 10 cm to a depth of 50 cm in three parallels with a soil probe. The moisture content of the soil samples was determined with oven method, drying the samples to constant mass at 105 ºC.

2.2.2. Penetration resistance test

The compact layers in the soil were examined with one of the most frequently applied method, that is, by determining penetration resistance. In the experiments penetration resistance was measured with a mechanical spring type soil penetrometer (DARÓCZI and LELKES 1999). Soil penetration resistance was measured during the vegetation period twice in 2004 (in June and in September) and three times in both 2005 and 2006 (in May, late August and October) in three parallels, at 10 cm intervals to a depth of 50 cm.

2.2.3. Examination of soil agronomic structure

The soil agronomic structure was examined by dry sieving. Soil structure tests were carried out on the six farms twice in 2004 (in June and September) and three times in both 2005 and 2006 (in May, August and October) in three parallels. The air-dried soil samples taken from the experiment sites were passed through 7 sieves of different pore sizes (20, 10, 5, 3, 1, 0.5 and 0.25 mm), thus dividing them into 8 size fractions. I measured the weights of the certain fractions and by expressing their amounts as m/m% I established the clod, crumb and dust composition of soil.

2.2.4. Economic assessment

The six family farms whose fields were involved in the experiment had no complete, authentic and reliable production and cost records for the years concerned. Consequently, for the experiment I chose one farm (experiment B) that had the most information of relevance for my economic analyses. During consultations with the selected farmers I collected the per-hectare data required for cost calculations in a data sheet. The farmer concerned was engaged in other business activities besides farming (trade in heating and construction materials) and the overhead costs were not separated between farming and the other activities. Since we had no overhead data for establishing the income from farming (i.e. for calculating the differences between production value and production costs - therefore I took the gross margin as the basis of the economic analysis.

The gross margin - that is, the difference between the production value and the direct variable cost - includes the profit of the sector and it also covers the fixed costs. Within the direct costs I considered the total material costs, the auxiliary operating costs, the crop unit price for the year concerned (HUF/t) and its yield (t/ha) as well as the production value that is the unit price multiplied by the yield.

2.3. Statistical evaluation

The soil moisture content, penetration resistance and agronomic structure were evaluated in an Excel worksheet. Single factor variance analysis was applied for statistical analysis (SVÁB 1981, BARÁTH et al. 1996).

3. RESULTS

3.1. Soil moisture content measurement results

3.1.1. Soil moisture content in the years under review

Significant differences were found between the experiments in 2004 (*Figure 1*) in the 10-20 cm layer ($SD_{5\%}$10-20=8), in the 20-30 cm layer ($SD_{5\%}$20-30=7.8), in the 30-40 cm layer ($SD_{5\%}$30-40=7.3) and in the 40-50 cm layer ($SD_{5\%}$40-50=3.9).

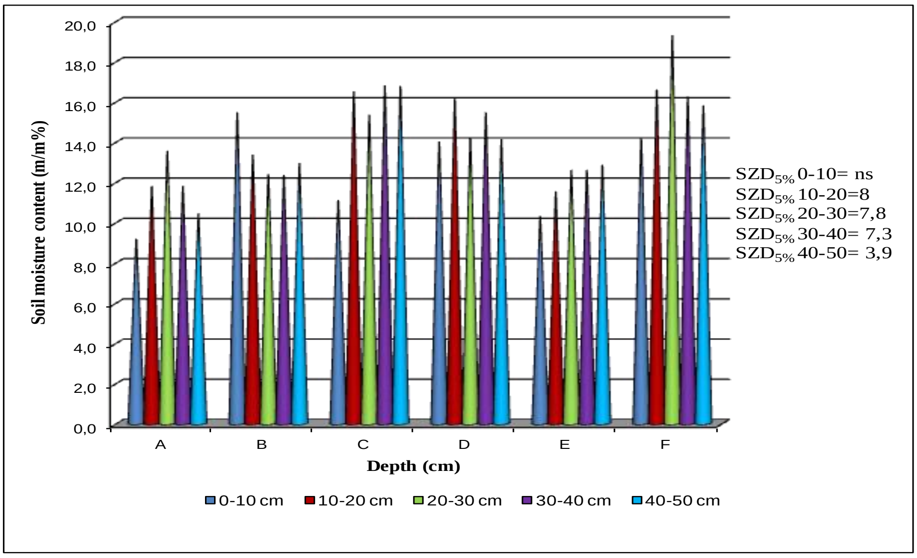


Figure 1: Soil moisture levels in the various experiments in the top 50 cm soil layer (2004)

Year 2005 witnessed the largest amount of precipitation among the three years under review (702.1 mm). Significant differences were found between the experiments in the 20-30 cm layer ($SD_{5\%}$20-30=1.7) and in the 30-40 cm soil layer ($SD_{5\%}$30-40=1.9) *(Figure 2).*

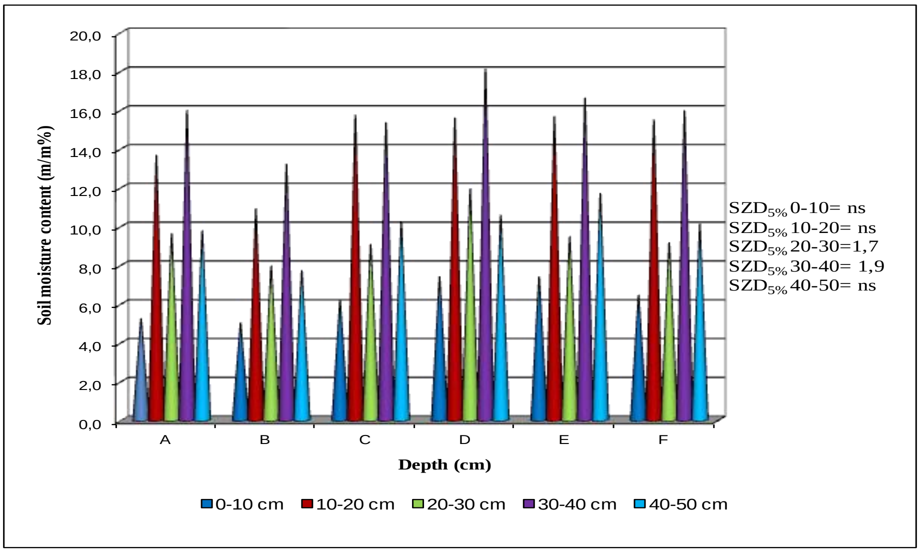


Figure 2: Soil moisture levels in the various experiments in the top 50 cm soil layer (2005)

The last year of the experiment was much drier (total annual precipitation: 559.3 mm) than the previous year. No significant differences were recorded in 2006 between the various experiments in any of the soil layers. (*Figure 3*) The highest soil moisture content was always found in the 30-40 cm layer. Similarly to year 2005, moisture levels were extremely low below 40 cm in 2006 as well. This may have been caused by a compact layer that impeded water transport below 40 cm.

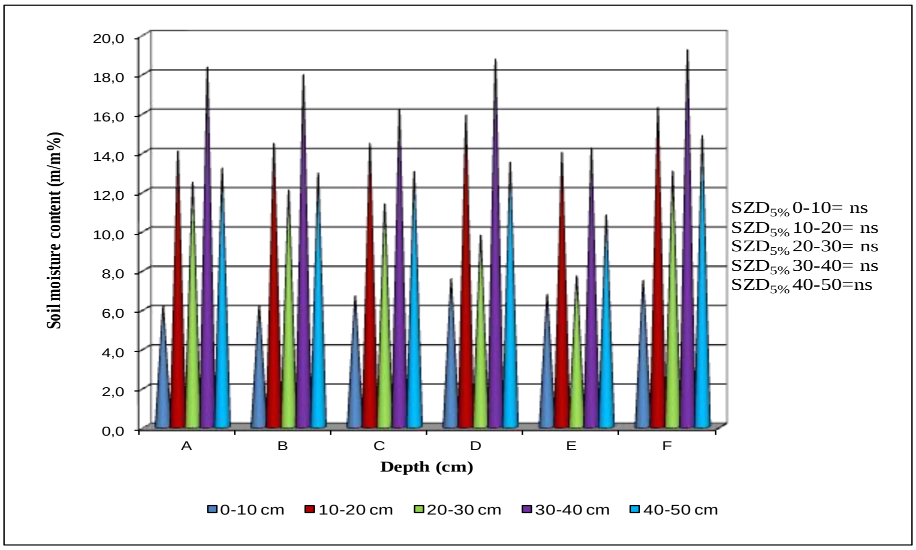


Figure 3: Soil moisture levels in the various experiments in the top 50 cm soil layer (2006)

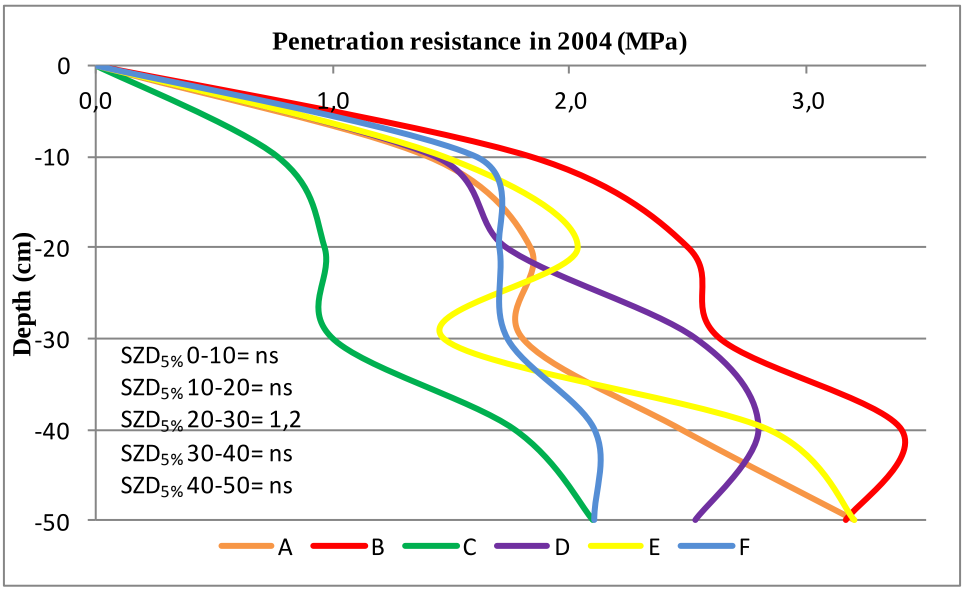
3.1.2. Evaluation of the soil moisture content results from a year effects point of view

In comparing the experiments of the certain years, significant differences were found at each depth, except for the 10-20 cm layer – that is the year effect was proven. The soil moisture content in the 10-20 cm layer depended not on the year effect, but on the tillage techniques applied. Accordingly, conventional tillage affected the soil moisture content in the 10-20 cm soil layer.

3.2. Penetration resistance measurement results

3.2.1. The results of penetration resistance measurements in the years under review

Significant differences were found between the experiments in terms of soil penetration resistance measurements in 2004 in the 20-30 cm layer ($SD_{5\%}$20-30=1.2). No statistically proven differences were found in the other soil layers. The soil penetration resistance values exceeded 3 MPa in experiments A, B and E. In the first year of the study the results showed that ploughing produced a sufficiently loosened soil structure at least to a depth of 30 cm in all of the treatments (*Figure 4*).

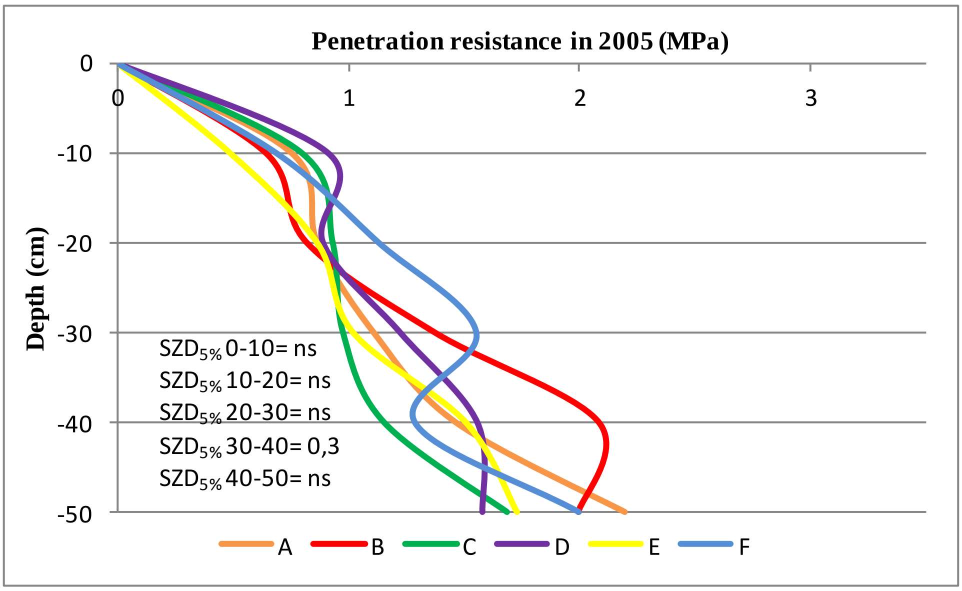


Soil moisture content in m/m % in the studied depths:

	A	B	C	D	E	F
0-10	9,2	15,4	11,1	14	10,3	14,2
10-20	11,8	13,3	16,5	16,1	11,5	16,6
20-30	13,5	12,4	15,3	14,2	12,6	19,3
30-40	11,8	12,3	16,8	15,4	12,6	16,2
40-50	10,4	12,9	16,8	14,1	12,8	15,8

Figure 4: Soil penetration resistance in the various treatments in the top 50 cm soil layer at the given soil moisture level (2004)

Significant differences were found in 2005 between the experiments ($SD_{5\%}$30-40=0.3) in the 30-40 cm layer *(Figure 5)*. In the second year of the study the results showed that ploughing produced sufficiently loosened soil condition to a depth of 30 cm in each of the experiments. In that year the average soil penetration resistance results were below 3 MPa in each experiment, indicating no adverse soil compaction. *Figure 5*, however, shows the depth where less optimal soil conditions were first detected. A plough pan layer was observed in the year under review below the depth of ploughing, and the soil penetration resistance values were below 3 MPa only as a result of the relatively higher soil moisture content. Soil loosening and varying tillage depth may be recommended to avoid tillage pan formation in the soil.



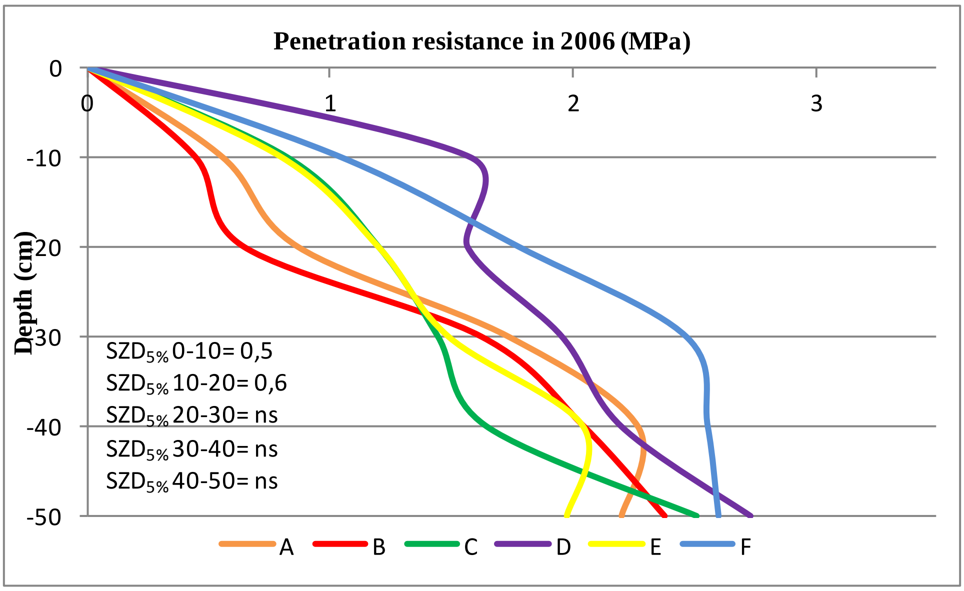
Soil moisture content in m/m % in the studied depths:

	A	B	C	D	E	F
0-10	5,2	5	6,2	7,4	7,4	6,4
10-20	13,7	10,9	15,7	15,6	15,6	15,5
20-30	9,6	7,9	9	11,9	9,4	9,1
30-40	16	13,2	15,3	18,1	16,6	16
40-50	9,8	7,7	10,2	10,6	11,7	10,1

Figure 5: Soil penetration resistance in the various experiments in the top 50 cm soil layer at the given soil moisture level (2005)

Significant differences were found in 2006 between the various experiments (*Figure 6*) in the top 10 cm layer ($SD_{5\%}$0-10=0.5) and in the 10-20 cm layer ($SD_{5\%}$10-20=0.6). In the last year of the study the results showed that soil penetration resistance increased in all cases as a consequence of several years of ploughing at the same depth. The so-called plough pan layer was detected in the soil below the depth of ploughing in the year concerned but the soil penetration resistance values were below 3 MPa owing to the soil moisture content.

To sum up the penetration resistance measurements, it can be concluded that in the case of the six examined field experiments significant differences were recorded at tillage depth in the first year, below tillage depth in the second year and in the top 20 cm of the soil in the third year. In the first year of the experiment higher than 3 MPa results were obtained in experiments A (in the 40-50 cm layer), B (in the 30-40 and in the 40-50 cm layer), and in experiment E (in the 40-50 cm layer). The average soil penetration resistance values for 2005 and 2006 were below 3 MPa in all of the experiments, but the presence of a compact layer could be observed below tillage depth as shown by the figures.



Soil moisture content in m/m % in the studied depths:

	A	B	C	D	E	F
0-10	6,2	6,2	6,7	7,5	6,7	7,5
10-20	14	14,4	14,4	15,9	14	16,3
20-30	12,5	12,1	11,3	9,8	7,7	13
30-40	18,3	17,9	16,2	18,7	14,2	19,2
40-50	13,2	12,9	13	13,5	10,8	14,8

Figure 6: Soil penetration resistance *levels in the various experiments in the top 50 cm soil layer at the given soil moisture level (2006)*

3.2.2. Evaluation of soil penetration resistance levels from a year effect point of view

The evaluation of soil penetration resistance from a year effect point of view was done by comparing the average soil penetration resistance results of the examined years. Significant differences were found between the years concerned at all depths ($SD_{5\%}$0-10=0.2; $SD_{5\%}$10-20=0.2; $SD_{5\%}$20-30=0.2; $SD_{5\%}$30-40=0.2; $SD_{5\%}$40-50=0.2), i.e. the year effect did have a great impact on the soil penetration resistance levels. However, no significant differences were found between the various experiments.

3.3. The results of the agronomic structure tests

3.3.1. Results of the soil agronomic structure tests

In year 2004 the crumb fraction of the soil accounted for 62.8-84.0%. Significant differences were recorded in the crumb fraction between the various experiments. ($SD_{5\%}$crumb=10.8). This was the year in which I found the largest clod fraction (14.5-35.0%) at the examined farms, and this was the year when the crumb fraction showed the highest heterogeneity between the experiments. The difference was significant for this fraction as well ($SD_{5\%}$clod=10.2). In year 2004 the ratio of the dust fraction varied between 1.5% and 6.1% at the different farms but no significant difference was found between the experiments *(Figure 7)*.

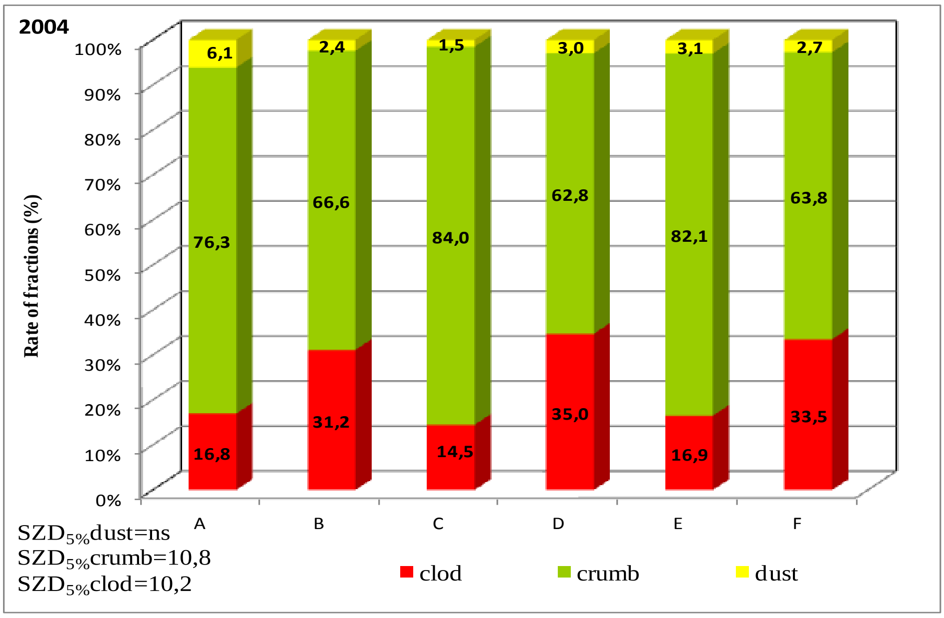


Figure 7: The agronomic structure in experiments A, B, C, D, E and F (2004)

In year 2005 the proportion of the crumb fraction was ideal for cropping (78.6-81.6%). In each experiment at least 80% crumb fraction ratios were found, except for experiment F. This is exceptional for Hungarian soils (*Figure 8.*). In the case of experiments A and B where crop rotation was applied (sunflower was produced on both farms in that year) the ratio of the clod fraction decreased more than it did in the other experiments.

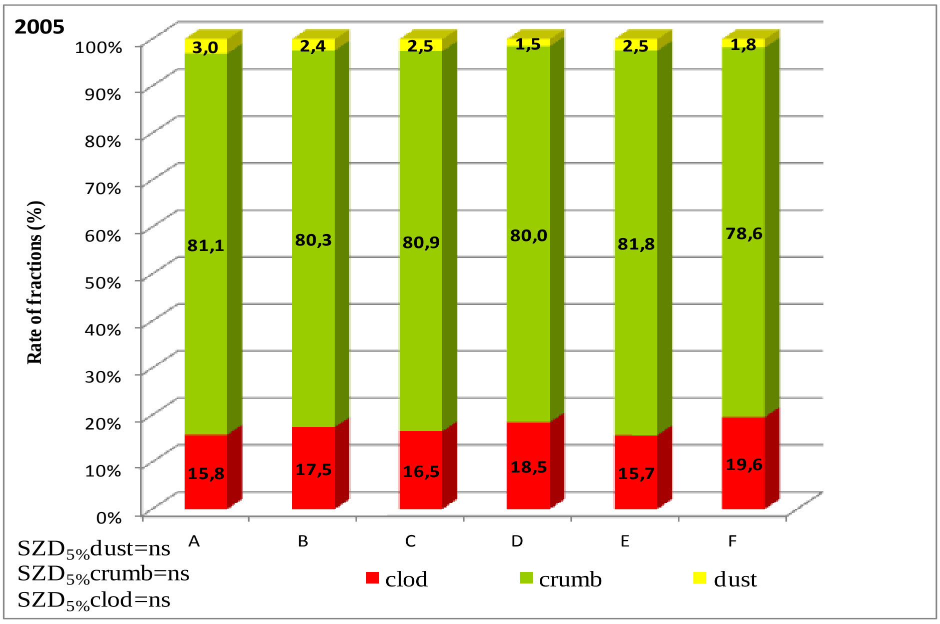


Figure 8: The agronomic structure in experiments A, B, C, D, E and F (2005)

It is concluded from the findings of 2006 that except for experiment B - the only case where crumb fraction increased - the clod fraction ratio varied the most in each experiment: apart from experiment B the ratio of the clod fraction grew in as compared to the previous year. During the three years of the experiments this was the year when the smallest dust fraction ratios were found, as it never exceeded 2% (1.3-2.0%).

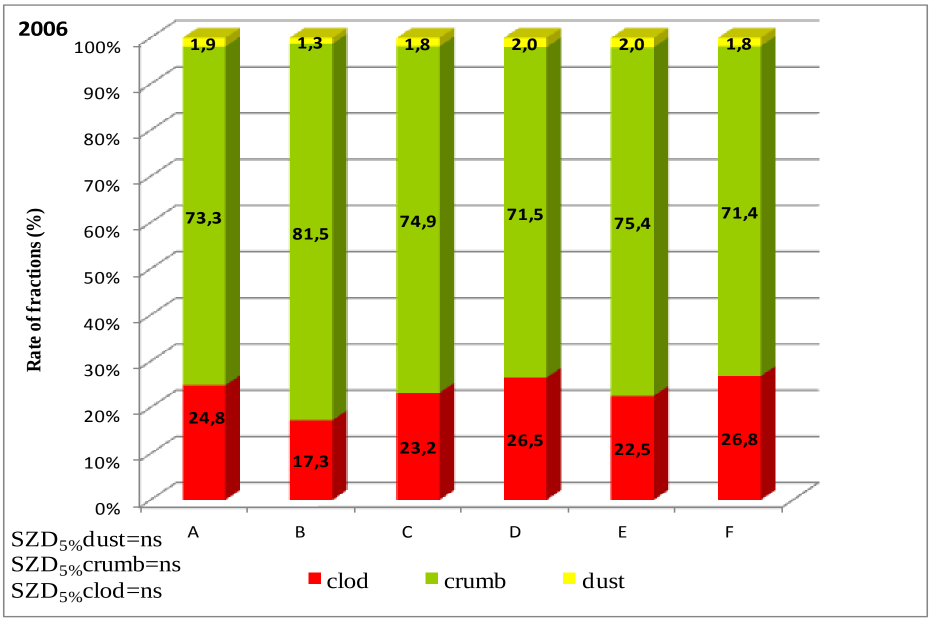


Figure 9: The agronomic structure in experiments A, B, C, D, E and F (2006)

3.3.2. Evaluation of the findings of the agronomic structure assessment, from a year effect point of view

No significant differences were found between the various years in any of the different soil fractions. The largest clod fraction was found in 2004 but no excessive clod forming was observed. The highest average ratio of the crumb fraction in the six experiments - the most favourable fraction for cropping - was found in 2005. Although this year saw the largest amount of precipitation of the three years under review, no statistically proven differences were found in this regard among the three years concerned. This may be explained by the fact that the land use affects agronomic soil structure on the long run.

3.4. The results of the economic analyses

3.4.1. Economic analysis of the applied conventional tillage technique

In the course of my economic analyses I took into account - within the direct costs - the total material cost, the auxiliary operating costs, the crop unit price in the year concerned (HUF/t), its yield and the production value calculated by multiplying one by the other, i.e. the sales revenue per hectare. Since the overhead figures were not available for the calculation of the income - for the establishment of the difference between production value and production cost - I choose the calculation of gross margin.

The gross margin was thus 100,098.5 HUF/ha in the case of maize in 2004, it was 41,596.4 HUF/ha in the case of sunflower in 2005 and 144.524 HUF/ha in the case of maize in 2006 - these amounts included the profit and covered the fixed costs.

3.4.2. A summary of the economic analysis

Figure 10 shows the gross margin figures - including area payments - for the various years under review.

The sum of area payment is also shown on a per-hectare basis, which is the ratio of the total area payment received by the farmer and the farmer's total farmed area. The figure shows the amount by which the gross margin (and thus the farmer's income) is increased by the area payment in the given year. In each of the examined years at least 25,000 HUF/ha area payment was added to the positive gross margin, increasing the farmers' per-hectare income. The figure shows the significant ratio of the income supplement provided in the case of sunflower which generated a modest gross margin in 2005. The most prosperous year from an economic aspect was the last year of the experiment. In 2006 maize production guaranteed the highest gross margins, which was completed by 37,000 HUF/ha area payment.

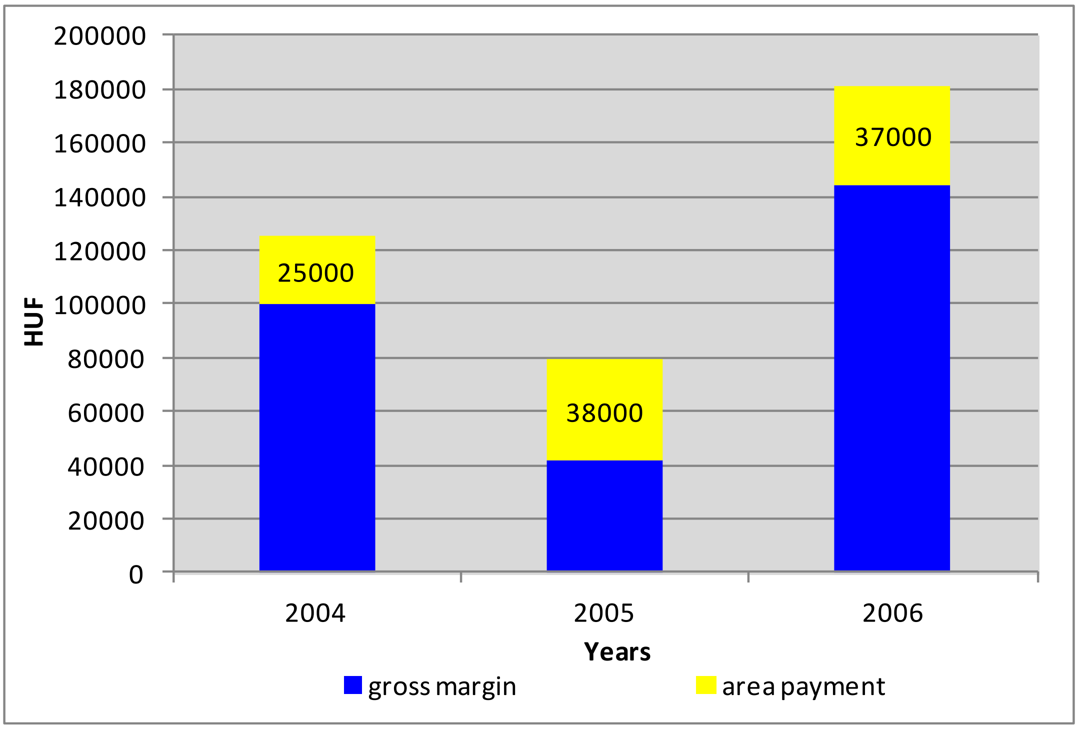


Figure 10: Gross margin and area payments per hectare (2004-2006)

Different field crops were grown on the experiment sites during the years under review (maize - sunflower - maize) but the auxiliary services were the same in each of those three years, i.e. there were no differences in the soil tillage technologies and the only - minor - differences were found between the fees charged for the services. Out of the direct costs, the auxiliary services were the highest in 2005 and 2006.

For the detailed evaluation of auxiliary operation costs *Figure 11* shows the per-operation breakdown. In each year primary tillage, based on soil inversion (ploughing) and harvesting accounted for the largest cost ratio within the auxiliary operational services. Disking, which was carried out after harvest but before ploughing, the application of fertilisers, seedbed preparation and sowing accounted for nearly equal amounts within auxiliary operating costs. The costs of crop protection includes the delivery of the chemicals used in the year concerned.

In the examined years the production of the selected crops - with conventional tillage, under the given site and weather conditions - secured the necessary gross margin, which not only evened the production costs but made the production profitable.

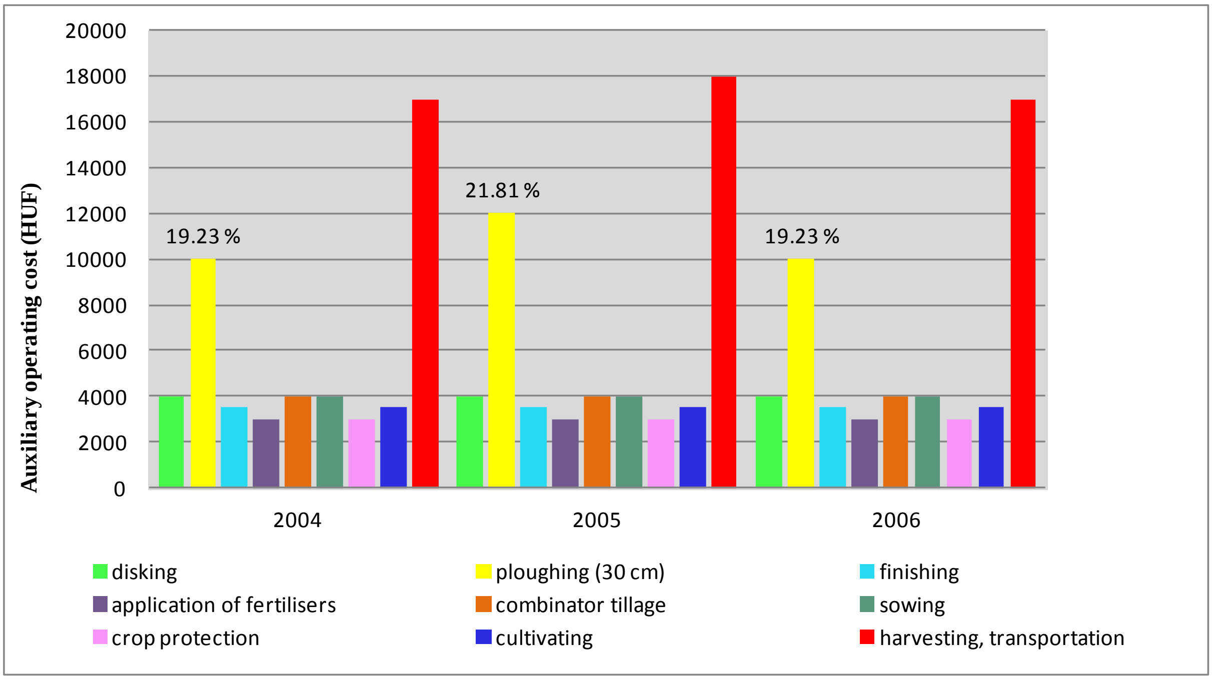


Figure 11: Distribution of the per-hectare costs of auxiliary services (2004-2006)

3.5. New scientific results

1. By three years of consecutive measurements on chernozem brown forest soil the tillage pan forming effect of ploughing was proven. Since the degree of compaction below the tilled layer never reached the critical level in any of the years concerned or by the end of the third year, I confirm that the risk of this typical soil structure defect can be reliably reduced, even if conventional tillage system is applied.

2. The presence of a plough pan layer was confirmed by the measurements of soil moisture content. Based on the magnitude of soaking of the soil below the ploughed depth, a modest unfavourable effect of the compact layer was verified.

3. My assessments of the agronomic soil structure helped to clarify the advantages, generally associated with conventional tillage. On the given soil type I confirmed the favourable impact of crop rotation on soil crumb conservation.

4. The climate-exposure of the top soil layer was verified by the year effect survey, which was supported by the results of the soil moisture content and soil penetration resistance measurements.

5. In view of the findings of my physical soil condition assessments I found that soil saving can be guaranteed to an extent that is typical of the system, even if properly applied conventional tillage is carried out.

6. My economic assessments again proved the high costs of conventional tillage within a cropping system. In the examined years the costs of conventional tillage were covered by the income of the crops produced.

4. CONCLUSIONS AND RECOMMENDATIONS

The land experiments – that form the basis of the present thesis - were set up between 2004 and 2006 in Pest county, at six farmlands around Pánd and Káva settlements. The findings, conclusions and recommendations are based on the present study and grouped according to the physical soil condition results and the conclusions of the economic analyses.

4.1. Conclusions and recommendations based on the studies and assessments of physical soil condition

The field tests focused - within the physical soil condition - on soil moisture content, soil penetration resistance and agronomic structure. One of the goals of the research was to sum up the findings concerning the physical soil condition in 2004-2006 under field circumstances and to evaluate the effects of conventional tillage on physical soil condition accordingly.

- The soil moisture content - regarding maize and sunflower production - remained unchanged in 2004 but decreased in 2005 and 2006 in each experiment below the depth of 40 cm. The extremely low soil moisture levels refer to impeded water transport below the depth of 40 cm. In the second - and rainiest - year of the experiment significant differences were found between the experiments in the 20-30 cm and 30-40 cm soil layers. At bottom layer of primary tillage, and right below that depth the differences in soil moisture levels must have been resulted by the timing and quality of ploughing. To avoid soil condition problems it is important that ploughing be carried out when it best suits the soil moisture content to make sure that the water infiltration is not hampered and soil can store water. If ploughing is carried out when the soil is humid, no large blocks and clods are produced. In 2006, the last year of the experiment, the soil moisture content at the depth of 40-50 cm was 51-57% higher than in the surface layer. This is assumed to have been a result of the increased loss of water and evaporation, caused by the absence of crop residues - no surface cover - and the larger soil surface produced by ploughing. It would be advisable to leave crop residues (mulch) on the soil surface, which would reduce evaporation, carbon-dioxide emission and surface erosion. Leaving a protective mulch layer on the soil surface will become increasingly important in the future as it plays an essential role in conserving soil moisture in addition to conserving the soil and the environment. In assessing the soil moisture content from a year effect point of it was found that in the 10-20 cm layer soil moisture content was determined not by the year effect, but by the tillage operations applied. Accordingly, the impacts of conventional tillage on soil moisture content appeared in the 10-20 cm soil layer.

- The soil penetration resistance tests indicated adversely compact layers below the tilled layer in three of the experiments in 2004. In the second year of the research I found significant differences between the experiments below the tilled layer (at 30-40 cm) in terms of penetration resistance but the average penetration resistance measurements values suggested that no adversely compact layers were found in any layers or in any of the experiments. In the last year of my research I found significant differences in the top 10 cm and in the 10-20 cm layer but no adverse compaction was indicated by the average penetration resistance measurement values in any of the experiments. The figures indicate, however, that a compact layer (plough pan) is present below the tillage depth, though due to the soil moisture content, penetration resistance was below 3 MPa. Conventional tillage applied over three years - in the course of which soil inversion based primary tillage (ploughing) was carried out to a depth of 30 cm each year - caused only minor soil compaction by the end of the period under review. Loosening and varying tillage depth from time to time may be necessary to avoid the tillage pan formation. The soil penetration resistance tests showed that ploughing had a positive impact to the depth of tillage under the given site and climate conditions. The favourable physical soil condition must have been a result of the optimised timing of tillage in terms of the soil moisture content as well as the soils' favourable physical properties. Significant differences were found between the various years in terms of soil penetration resistance. The weather conditions of the examined years were found to have had a major impact on soil penetration resistance values. Similar conclusions were drawn by BEKE (2006), LÁSZLÓ (2007) and MIKÓ (2009) as well.
- The agronomic structure tests showed that the clod fraction ratio decreased and the crumb fraction ratio - which is the most useful fraction for cropping - increased where the crop rotation was applied for the successive years. Crop rotation produced a better clod fraction ratio than growing the same crop year after year.
- My measurements proved that the crumb fraction ratio did not drop below 70% in any of the experiments by the end of the third year of my research. Thus the conclusion was drawn that no harmful clod forming was caused by conventional tillage. This must have been a result of ploughing at the optimal soil moisture content. Since the applied land use practices affect the soil structure over time, tillage to the same depth year after year increases the risk of compact layers appearance in the soil, therefore it is advisable to apply soil structure conserving tillage techniques and vary the tillage depth from time to time.

- The unfavourable impacts of ploughing were observed in the course of the agronomic soil structure assessment. During the soil excavation it was observed that ploughing based tillage reduced the earthworm counts from year to year, since the soil inversion based tillage inevitably destroys earthworm tunnels. In view of earthworms' crucial role in maintaining soil fertility, the application of tillage systems based on primary tillage without soil inversion is recommended in order to provide earthworms with a favourable habitat.

4.2. Conclusions and proposals on the basis of the economic assessment

No comprehensive, authentic and reliable production and cost records could be found on the six family farms, therefore I chose the one that had the largest amount of data of relevance for my economic analyses. I chose the gross margin as a basis for economic analyses, since there were no accurate data on overhead costs.

- In analysing the gross margin I found that its amount not only covered the direct production costs during the years under review but it always provided the farmer profit as well, in addition to covering the overhead costs in each year concerned. From an economic aspect, conventional tillage was a favourable option for the production of the crops concerned under the given site and climate conditions.
- In reviewing the auxiliary services I found that primary tillage, based on soil inversion (ploughing) and harvesting, accounted for the highest proportion of the costs in each year concerned. Some 19-22% of the auxiliary operational costs were spent on ploughing in those years. The profitability of cropping is heavily affected by the energy consumption and costs of tillage. In view of the soil physical condition findings it is questionable whether it is really necessary to apply the expensive, less environment preserving primary tillage, based on soil inversion, year after year.
- In view of the impacts of conventional tillage on physical soil condition, and the findings of the economic analyses (also in view of aspects of soil conserving and economic efficiency), it seems to be highly probable that the application of a tillage system without soil inversion could be very successful on my experiment sites. The best solution could be choosing a tillage technology that would maintain and even improve the soil structure, leaving crop residues on the soil surface in contrast to conventional tillage, whereby it would even contribute to reducing soil moisture loss. Accordingly, a primary tillage system based on the cultivator as the key tool for tillage could be suitable for cropping on the chosen

experimental sites. Though its application needs more care and attention as well as expertise, in addition to conserving the soil structure it properly loosens, crumbles and mixes the soil, thereby creating ideal conditions for the crops to be produced. Before selecting a tillage method, however, economic calculations should be carried out for the possible non-inverting tillage systems as well in order to ascertain whether the soil and environment conserving tillage system that is to be adapted on the given site would turn out to be more profitable than conventional tillage while taking into account the market conditions as well.

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