Theses of Doctoral (PhD) dissertation

COMPLEX ANALYSIS OF THE CONVENTIONAL AND REDUCED TILLAGE SYSTEMS OF MAIZE

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1. PRELIMIARIES AND OBJECTIVES OF THE DOCTORAL THESIS

The largest proportion of modern, developed societies face serious agricultural difficulties. Unforeseeable, fluctuating purchase prices, periodic overproduction, increase of meteorological extremities, degradation of arable land (physical, chemical and biological degradation), strict legal background and high costs are all factors which influence the profitability of crop production. As a result of its natural endowments, Hungary is a basically agricultural country; one of our most important resources is arable land. Therefore it is unimaginable that agricultural production might not play a decisive role in the economic life of Hungary one day. In terms of the future, it is essential to develop agro-technological solutions which improve the competitiveness of agricultural enterprises; this is based on the short and long term thrift and effectiveness of the crop production sector. Sustainable development in plant production demands adaptation to ecological and economic conditions, namely the overall consideration of the production site characteristics, harmonisation of production demands and environmental objectives, the minimal pressure on environment and economic operation.

The explosion of oil prices in the 1970s and the continuous price increase of the inputs of plant production highlighted technical and agronomic research and technologies by means of which the energy demand of plant production might be reduced. As a result of technological development within agriculture (more effective chemicals, artificial fertilisers and technical developments) it became possible for reduced pass and plough-less tillage methods to achieve yield levels similar to conventional farming with less energy consumption. As a result of precision farming related technological developments which are based on positioning, such applications became available for producers which are able to significantly contribute to the effectiveness of production.

The general objective of my doctoral thesis is the analysis of application possibilities of strip tillage on the basis of agronomic and economic standpoints. In my thesis a selected parameter-based comparative analysis of strip tillage, subsoiling and winter ploughing systems has been carried out on the basis of the data of 3 years (2012-2014). My objective is the complex analysis of each tillage system with the involvement of different disciplines as well as the introduction of results that are utilisable in practice.

2. RESEARCH METHODS

2.1. Introduction of research conditions

The trial database of the Institute of Land Use, Technology and Regional Development of DE AGTC and KITE cPlc. was used for the analysis of different tillage variations for maize *(Zea mays L.)* indicator. The trial field is situated at the peripheral area of Kenderes on meadow chernozem soil. The analysis of 3 different tillage trials has been carried out on the plot; 4.5 hectares have been treated with winter strip primary tillage, 4.5 hectares with winter ploughing and 4.5 hectares with subsoiling. There are 9 varieties, 3 plant density, 3 nutrient and 4 plant protection trials in every primary tillage method. Their harvesting took place separately; the average of these data has been used for the evaluation of primary tillage methods. Primary tillage was carried out at a soil moisture condition which is required for optimal cultivation, while sowing was carried out on the same day in the case of every variation.

In the first year, the green crop of all three analysed technologies was winter wheat. Harvesting of winter wheat was directly followed by shallow (5 cm) stubble-stripping and later during the summer by chemical stubble treatment. Prior to the winter ploughing and subsoiling primary tillage, complex artificial fertiliser has been applied, while in the case of the strip technology basic fertilisation took place together with primary tillage. Ploughing has been finished during autumn in a separate pass, while in the case of strip tillage and subsoiling the finishing process was carried out together with primary tillage. Sowing took place at the same time in April in the case of all three tillage systems. Soil disinfection, strip spraying and the application of the starter fertiliser were carried out together with the sowing. Mechanical plant treatment took place twice after sprouting, completed with the application of nitrogen fertiliser in both cases. Harvesting was carried out at the same time in every tillage system.

In the next two years of the trial, primary tillage was done after the harvesting of maize. The technology is identical to the previously introduced one; the only difference is that there was no stubble treatment following the harvesting of the maize green crop and harrowing. The first operation after these was the application of artificial fertiliser in the case of the ploughing and subsoiling technologies, while in the strip system it was primary tillage with the application of artificial fertiliser.

2.2. Determination of soil moisture in the analysed years

In the first year of the analyses, determination of soil moisture was carried out on the basis of small cartridge (100 cm^3) sampling. After the transportation of the undisturbed soil samples to the laboratory, their weight has been determined then they have been dried to weight balance at 105°C, finally the volume percentage moisture content has been determined.

In the second and third years soil moisture determination was carried out by means of the FIELD SCOUT TDR 300 soil moisture probe. Soil moisture measurements took place prior to sowing. 50-50 measurements have been completed in the ploughing tillage, subsoiling and strip tillage technologies. Following the stabilisation of the probe-rods within the soil, the indicated return times have been recorded by measurements; on the basis of these data soil moisture content has been determined following calibration.

2.3. Determination of grain moisture content of maize

In order to determine the grain moisture content of maize within each tillage variation, there was a sampling during harvesting. The samples have been collected from every plot of the tillage versions, during the unloading of the harvester. 1-1 kg of sample has been collected from each plot, thus the basis of analyses was 19 kg of average sample from each primary tillage method.

Moisture content after harvesting was determined by means of a FOSS Infratec 1241 cereal analyser. The device separated the samples to 5 additional subsamples, consequently 95 (19x5) measurements were available for analysis from each tillage variation.

2.4. Determination of the calibration curve of TDR 300

Each tillage variation was described through return time by the measurement results of the TDR 300 soil moisture probe. To convert these values into volume percentage moisture content, the completion of a series of calibration moisture data was necessary. There was a sampling on the analysed area prior to sowing. The trial areas was considered pedologically homogenous, therefore the average sample was a mix of the samples of from the three tillage variations. 15 kg of average sample has been assembled from the samples collected form the same depth (0-20 cm), then it was transported to the laboratory and dried down. The dried soil was then finely ground.

For the creation of the calibration curve, the average sample (originating from the upper soil layer (0-20 cm) of the trial area) has been mixed to a defined moisture level and loaded into known volume measurement cylinder. In the course of creating the moisture series, the accuracy of the calibration curve was continuously verified with an Ohaus MB45 moisture analyser. Following the execution of the measurement series, the data was recorded in a Microsoft Excel 2007 table. The illustration of the data in a chart (measurement time on the X axis and volume percentage moisture on the Y axis) resulted in the calibration curve. A linear trend line was added to the measurement data.

2.5. Determination of soil penetration resistance by means of a penetrometer

Determination of soil penetration resistance was done by means of a Penetronik penetrometer. Measurements have been carried out at the same location every year on the basis of GPS coordinates. In conformity with the doctoral thesis of RÁTONYI (1999) 15-15 measurements have been carried out in each treatment on defined sized homogenous plots. The longitudinal tillage profiles were completed after 30-30 measurements. The distance between each measurement spot was 15 cm. This meant the recording of a 4.5 m long soil profile in the case of each primary tillage method. In the case of the strip tillage the first and last measurement points are the geometrical median line of the uncultivated strips. The graphic visualisation of soil profiles was carried out in Microsoft Excel 2007 by means of interpolation.

2.6. Statistical analyses

Determination of the minimum number of measurements for soil moisture measurements was executed on the basis of the method of SVÁB (1981):

$$n=\frac{t_{p\%}^{2}\times s^{2}}{h^{2}}$$

Where:

n = minimum number of measurements

tp% = critical value of the t-test with a certain probability and degree of freedom

s = deviation

h = estimation error

Every statistical analysis was completed with the 'agricolae' package of the R statistical software. The comparison of mean values was done with Duncan-test on a 5% significance level. According to the analysis of variance, there was no significant difference between treatments indicated with the same letter in figures and tables. Tables and figures were produced in Microsoft Excel 2007.

2.7. Economic analyses

As a first step of the economic analyses, the cost-income analysis of each tillage method was carried out. The data required for the analyses was provided by Kenderes 2006 Ltd. and KITE cPlc. The fuel consumption of each tillage system was determined on the basis of average fuel consumption of the 3 years. In terms of personnel costs and other costs an annual 5% of cost increase was used, while the calculation of material and overhead costs was based on the database of KITE cPlc. For the sales price of maize the actual market price was used which was 63,000 Ft/t in 2012, 40,500 Ft/t in 2013 and 35,500 Ft/t in 2014. For the determination of drying costs 1,200 Ft/t, for cleaning cost 56 Ft/dried water kg and 500 Ft/t loading and unloading costs were used. The calculation of the volume of dried water was based on the MSZ 6367-3:1983 standard.

In the course of the investment-return analyses, the starting cash flow of investments was based on the purchase price of the equipment required for the implementation of the technology. In the ploughing variation this value is 26,960,000 Ft (sowing machine, field cultivator), in the subsoiling variation it is 31,460,000 Ft (finisher, sowing machine, field cultivator), while in the case of strip tillage it is 36,960,000 Ft (strip tillage equipment, sowing machine, field cultivator). For the calculation of income per hectare the average of income during the three years was used in all three cases. For the cash flow of each year 50% of the income was the base value, which constituted the financing of the investment. 4% calculative interest rate was used for the calculations. For the economic evaluation of each tillage technology investment internal rate of return, net present value, profitability index and dynamic return time were used.

3. RESULTS

3.1. Determination of the minimum number of measurements

The data of the trial measurements contain more or less errors, namely the results of certain multiple times repeated measurements are slightly different; the results show deviation. Therefore, the error of the estimated value of the analysed parameter needs to be decreased below a certain level. In the course of the soil moisture measurement with the TDR 300 soil moisture probe the imperfection of the measuring device, the variability of trial conditions (soil heterogeneity) and the execution of the measurement are the reasons for the deviation. The function of the minimum number measurements which is based on the estimation error of the period time is shown by *Figure 1*. The chart shows that through the application of a higher number of repetitions estimation errors can be reduced. According to the period, a total of 8 measurements are required for achieving a 5% estimation error, while 2 measurements are capable of 10% accuracy.

During the on-site measurements, the TDR 300 soil moisture probe indicates period as a result referring to measurement. In order to convert this data to volume percentage moisture content the calibration curve of the 0-20 cm soil layer of the sample area had to be elaborated (*Figure 2*).

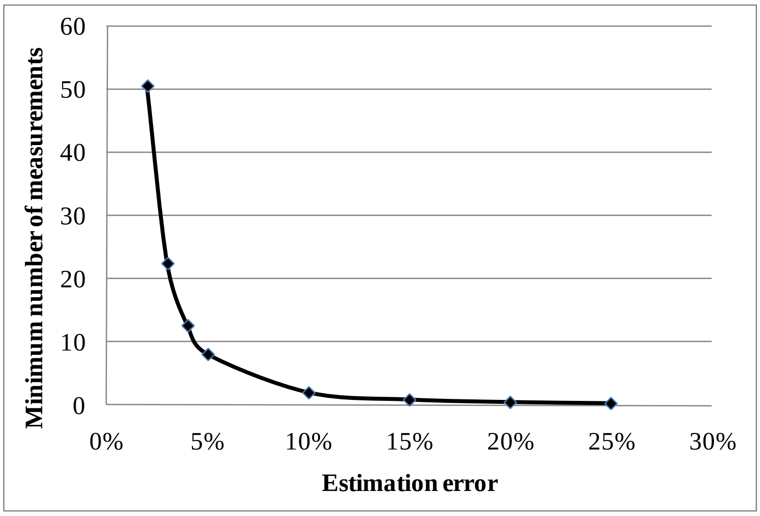

Figure 1 Estimation error of soil moisture determination as a function of sample number on the basis of period

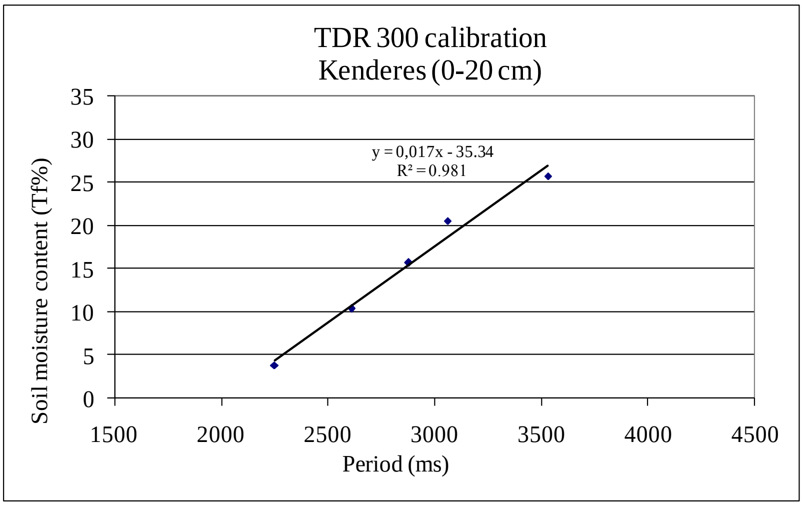

Figure 2 Calibration curve of the TDR 300 soil moisture probe with respect to the trial sample area

Figure 3 shows the estimation error of determining the soil moisture content as a figure of sample number on the basis of volume percentage moisture results. If estimation accuracy is determined on the basis of the period, the above introduced number of measurements (8) which is required for achieving the 5% estimation error according to the period, it would be 10-15% in terms of the estimation error of the volume percentage moisture content. For the more accurate determination of volume percentage moisture content the minimum number of measurements needs to be significantly increased. While 202 measurements are required for achieving a 1% estimation error according to the period, this value is 1060 if it is determined on the basis of volume percentage moisture content.

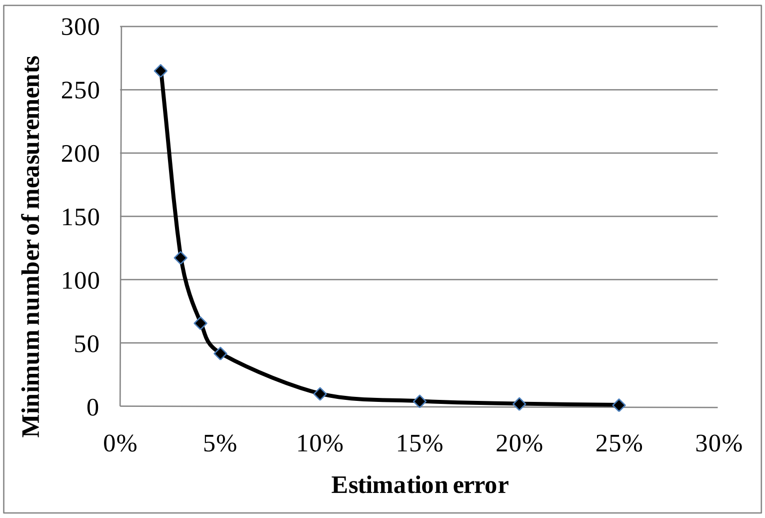

Figure 3 Estimation error of determining soil moisture content as a figure of the number of samples, on the basis of volume percentage moisture content results

3.2. Moisture content of the analysed tillage systems prior to sowing

In 2012, determination of soil moisture content prior to sowing was determined through undisturbed sampling within the 0-10 cm layer of the soil. The results of measurements for each tillage system are shown in *Figure 4*. In 2012, the lowest soil moisture was recorded in the winter ploughing primary tillage (18.24%), this was followed by the cultivated strip of strip tillage (19.2%) and subsoiling (19.7%), however the difference amongst these treatments was insignificant. The highest soil moisture was recorded in the area of strips within the strip tillage system (22.97%), which was a statistically verifiable difference compared to the others.

In 2013, the lowest moisture value was measured in the case of winter ploughing (20.56%), which is significantly lower than the values of the rest of the systems. There was no statistically verifiable difference between the soil moisture of subsoiling (24.22%) and the sowing strip of strip tillage (24.57%). The highest moisture content was recorded in the area between the strips of the strip tillage system (30.23%), which significantly exceeded the values measured in the case of subsoiling and ploughing (*Figure 5*).

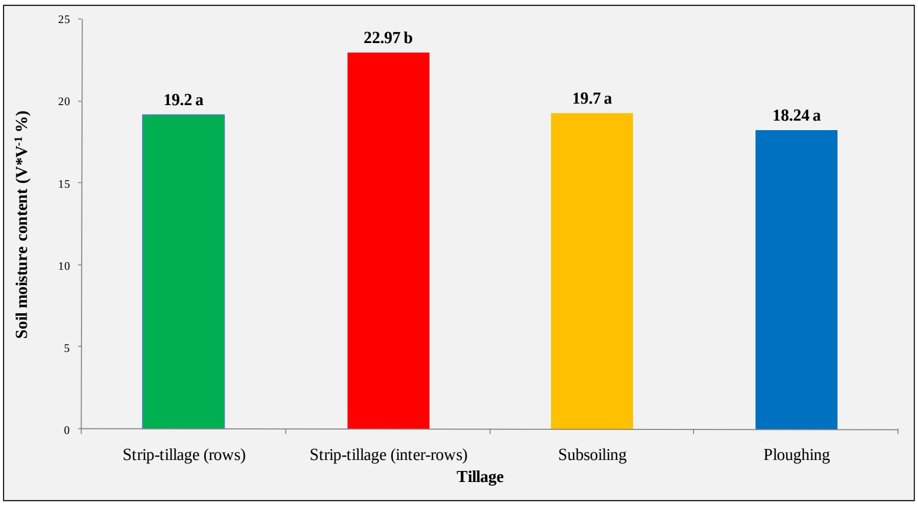

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Figure 4 Soil moisture content measured within the 0-10 cm layer in each tillage system prior to sowing (Kenderes, 2012)

In 2014, there were statistically verifiable differences in terms of the moisture content of the 0-20 cm soil layer of each tillage system. The moisture content of the ploughing system (24.54%) was significantly exceeded by the other tillage systems.

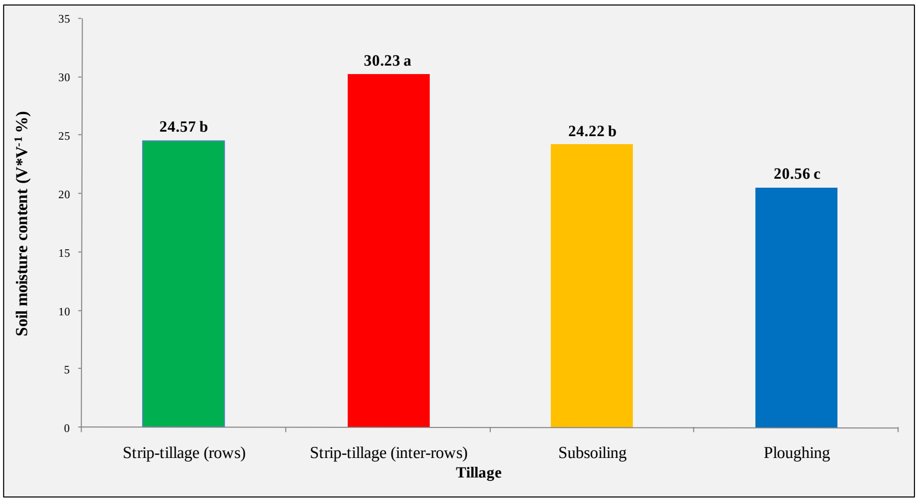

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Figure 5 Soil moisture within the 0-20 cm soil layer prior to sowing (Kenderes, 2013)

There was no real difference between the moisture content of subsoiling (26.74%) and the cultivated strip of strip tillage (26.85%). The moisture content of the area between strips of strip tillage (31.33%) significantly exceeded that of subsoiling and ploughing tillage (*Figure 6*).

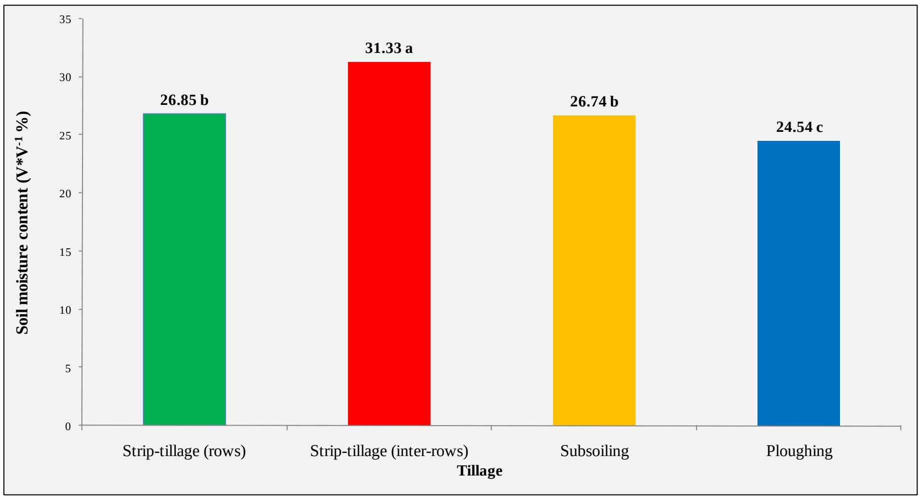

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Figure 6 Soil moisture content within the 0-20 cm layer prior to sowing (Kenderes, 2014)

3.3. Penetration resistance of the soil in the case of applying different tillage methods

The measured soil penetration resistance at the Kenderes trial location is different in terms of the used tillage systems. Measurement of the penetration values took place within the 0-60 cm soil layer; the analysis contains the comparison of the 10 cm soil layers.

In the case of strip tillage, the basis of comparison is the cultivated strip. In 2012, none of the soil penetration resistance values measured in each primary tillage type exceeded 3 MPa, either in the cultivated layer or the soil layer below that. On the basis of the results prior to sowing in 2012, there was a significant difference amongst the three analysed tillage methods in every soil layer (*Figure 7*). Penetration resistance increases in parallel with the depth of cultivation, there are no compacted layers in the 60 cm soil depth.

The curves of penetration resistance measured in 2013 are included by *Figure 8*. The figure shows that there is no significant difference in the upper 20 cm layer of the cultivated soil in terms of soil penetration resistance of the different tillage methods. Well separable soil resistance values can be recorded in the soil layers below 20 cm in terms of the tillage types; ploughing tillage has the lowest, while the cultivated strip of strip tillage has the highest penetration resistance. Below the 20 cm layer, significant difference can be recorded amongst all penetration curves.

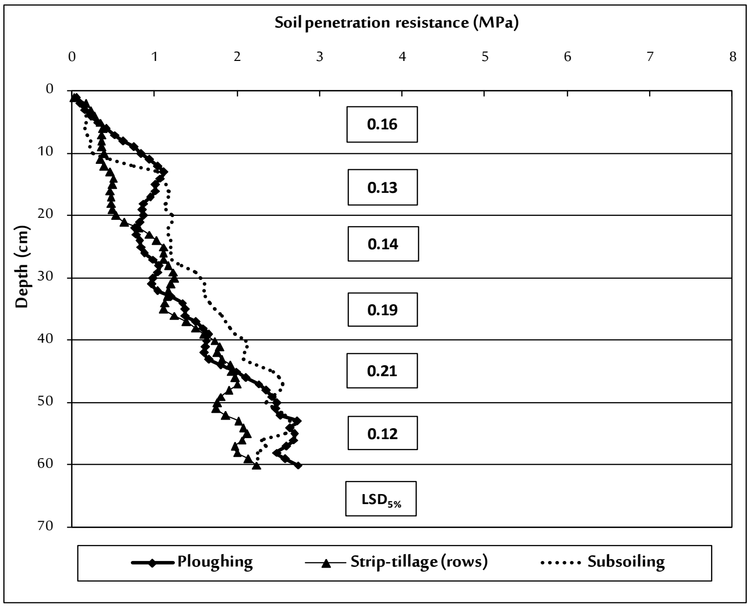


Figure 7 Soil penetration resistance measured in each tillage system (Kenderes, 2012)

Figure 9 shows the soil penetration resistance values measured in 2014. Except for the soil penetration resistance values measured within the 0-10 cm and 30-40 cm soil layers, significant differences can be detected amongst the tillage variations. The values of the penetration curve within the cultivated layer are the lowest in the case of ploughing tillage variation, which is significantly exceeded by that of strip tillage and subsoiling. There was no soil penetration resistance value exceeding 3 MPa with the analysed layer.

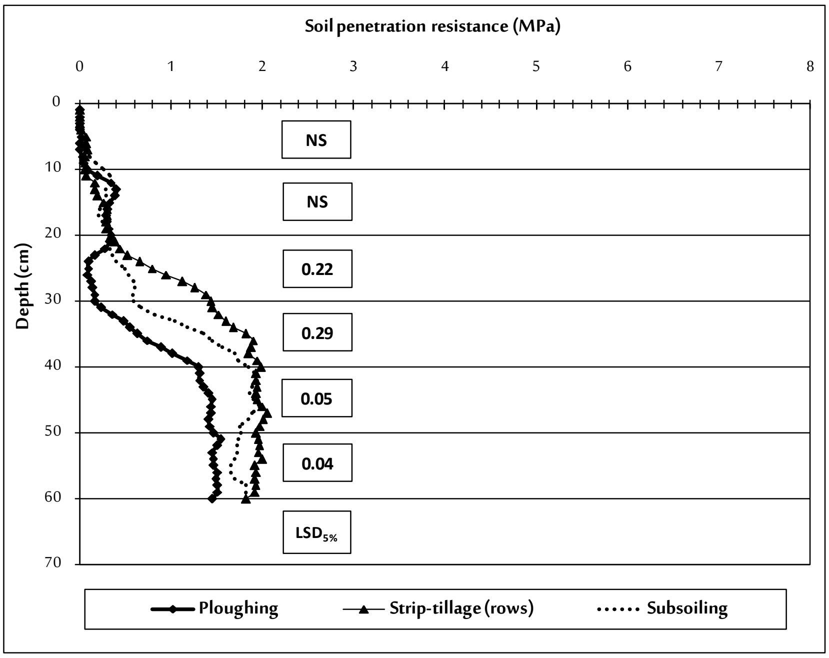


Figure 8 Soil penetration resistance measured in each tillage system (Kenderes, 2013)

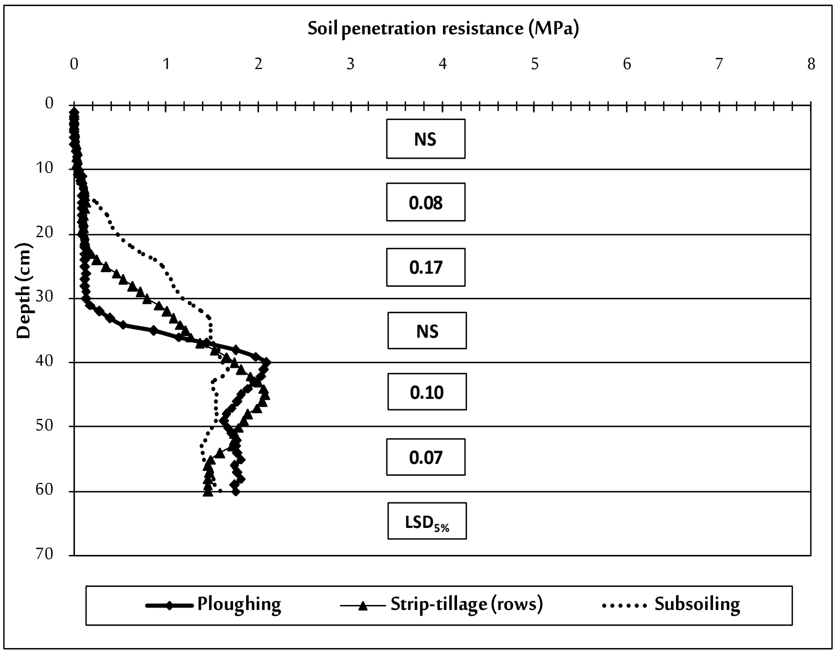


Figure 9 Soil penetration resistance measured in each tillage system (Kenderes, 2014)

Every year, the longitudinal profile of each primary tillage method is completed by means of a penetrometer. *Figure 10* shows the soil preparation resistance profile of the strip tillage system in 2014, prior to sowing. There is no difference within the upper 10-15 cm layer of strip tillage; however below that layer the cultivated and uncultivated soil strips are clearly separated. Soil penetration resistance of the cultivated strip indicates loose soil condition also within the soil layer below the cultivated strip, which represents the breaching effect of the subsoiling equipment.

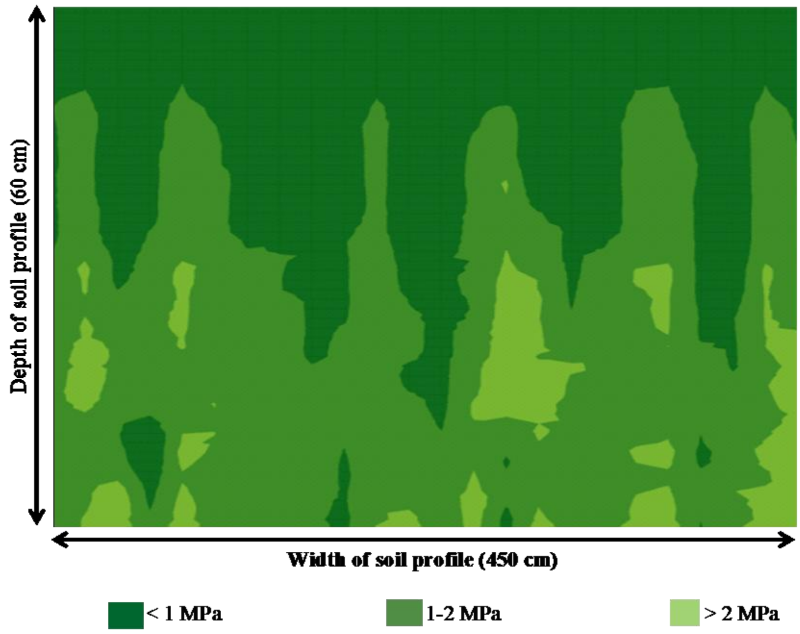
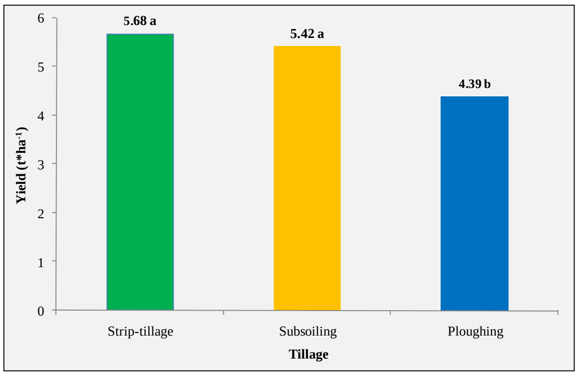


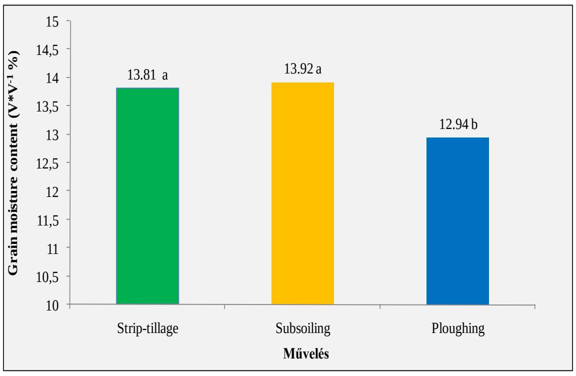
Figure 10 Soil penetration resistance profile of strip tillage prior to sowing (Kenderes, 2014)

3.4. Grain yields and grain moisture content measured in the case of different tillage systems

After harvesting, the yield and grain moisture content of each tillage system has been determined. Yield and grain moisture content are two indicators of maize production which fundamentally determine the effectiveness and profitability of different tillage systems.

2012 was an extremely droughty year, which is well represented by the yield results. Yield of different tillage systems is shown by *Figure 11*. The highest yield was measured in strip tillage (5.68 t/ha), which was followed the yield of subsoiling (5.42 t/ha), however there was no statistically verifiable difference between the two treatments. The lowest yield was realised in the ploughing variation (4.39 t/ha), which was approximately 30% below the yield of strip tillage and 23% below subsoiling.





Columns marked by the same letter have no significant difference according to Duncan's test at α=0.05

Figure 11 Grain yield measured in the case of the application of different tillage systems at standard grain moisture content of 14.5% (left) and the grain moisture content by the time of harvesting (right) (Kenderes, 2012)

Moisture content of the grain yield influences profitability of maize production, since it is necessary to dry in order to storage securely. Following harvesting, the moisture content of the maize yield of each tillage system was determined by means of a FOSS Infratec 1241 cereal analyser. As a result of the droughty year of 2012, the grain moisture content by the time of harvesting was below the practically usual 18-20%. The highest moisture content was recorded in the case of subsoiling (13.92%), it was followed by strip tillage (13.81%); between which there was no significant difference. The grain moisture content measured in the ploughing treatment was significantly lower compared to the primary tillage methods without ploughing; grain moisture content in the case of ploughing primary tillage was approximately 1% lower *(Figure 11).*

Precipitation conditions of 2013 were more favourable than that of 2012 in terms of maize production. The achieved yield in each tillage system was almost double of the yield of the first year in the survey. The highest yield was realised in subsoiling primary tillage (10.57 t/ha), followed by ploughing tillage (10.56 t/ha). The lowest yield was recorded in strip tillage; however the yield difference amongst each treatment is not significant (*Figure 12*).

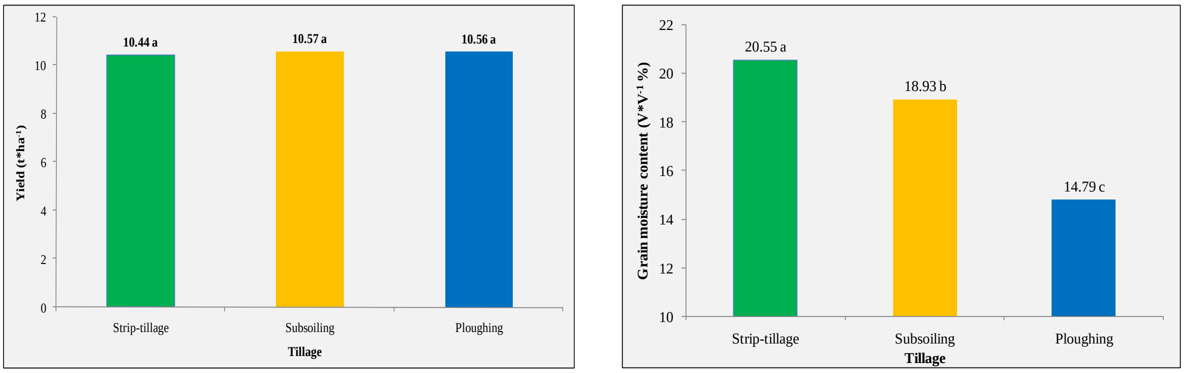


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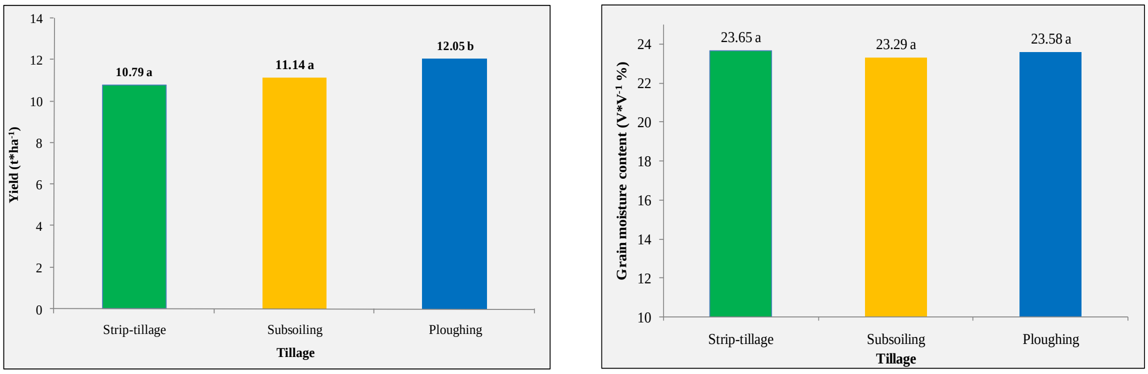
Figure 12 Recorded yield in the case of different tillage systems at standard moisture content of 14.5% (left) and moisture content by the time of harvesting (right) (Kenderes, 2013)

Contrary to yield, there are significant differences amongst the tillage systems in terms of the grain moisture content of maize. The difference is significant in the case of every treatment. The highest moisture content was recorded in the case of strip tillage (20.55%). The grain moisture content of subsoiling was 1.6% lower (18.93%), while the value measured in the case of ploughing (14.79%) was approximately 5.6% lower than the moisture content of strip tillage (*Figure 12*).

In 2014, there was no significant difference amongst the yield of plough-less tillage systems, however the yield of ploughing primary tillage statistically exceeded the yield of strip tillage and subsoiling technologies (10.79 t/ha), this was exceeded by ploughing technology (12.05 t/ha) by 11 %. (*Figure 13*).

In terms of the grain moisture content of each tillage variation, the year 2014 was different in comparison with the previously analysed years. Although the absolute value of grain moisture content was the highest in the case of strip tillage, there was no statistically verifiable difference amongst the tillage variations. In terms of the grain moisture content of the analysed years, the values recorded in 2014 exceeded the values of the previous years (*Figure 13*).



Columns marked by the same letter have no significant difference according to Duncan's test at α=0.05

Figure 13 Recorded yield in the case of different tillage systems at standard moisture content of 14.5% (left) and moisture content by the time of harvesting (right) (Kenderes, 2014)

3.5. Economic analysis of each tillage system

Fuel consumption of each tillage system has significant differences in terms of both the amount required for primary tillage and the amount required for the entire technology, which is represented by *Figure 14*. The fuel demand of strip tillage (11 l/ha) is more than 60% less, than that of the winter ploughing technology (30 l/ha), while the amount of fuel used for subsoiling (17 l/ha) is approximately 40% lower than the amount used for ploughing primary tillage. In terms of the fuel demand of the entire technology, strip tillage is the most favourable (63.1 l/ha), followed by subsoiling (77.6 l/ha). The highest fuel consumption was recorded in the case of the ploughing technology. Fuel consumption of plough-less tillage technologies is approximately 35% (strip tillage) and 20% (subsoiling) lower, than that of ploughing tillage. The reason of that is the difference caused by the energy demand of primary tillage; however the application of cultivation technologies implemented with less passes mean fuel saving.

The cost analysis of the involved tillage systems and the related important economic indexes are included by *Table 1*.

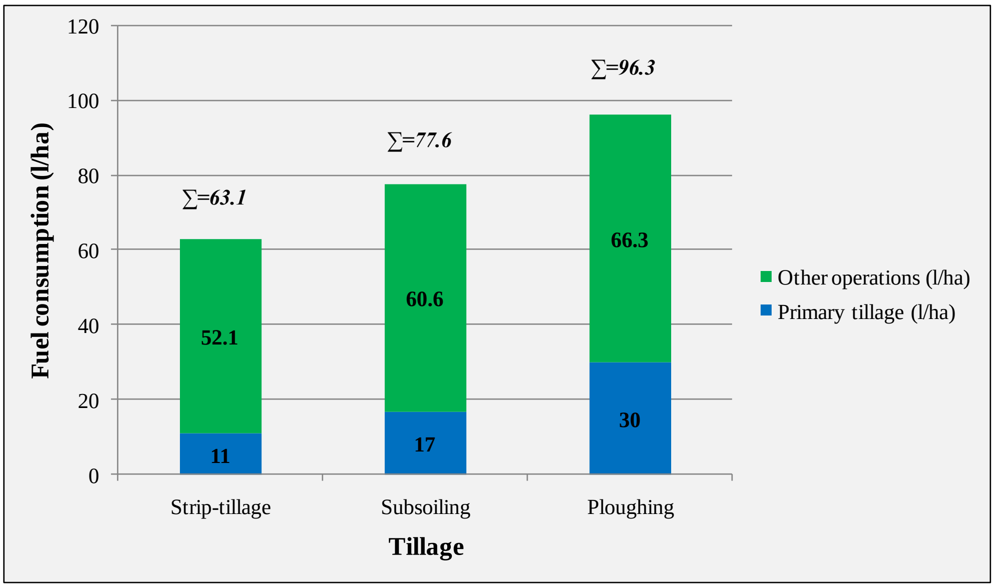


Figure 14 Average fuel consumption of each tillage system

In 2012, the differences of mechanical labour costs were significant. The most important difference was recorded amongst the costs of primary tillage. Amongst the mechanical operations, leaving out the finishing of primary tillage in the case of subsoiling and in the case of strip tillage the saving of the cost of fertilisation, finishing of primary tillage and seed bed preparation have been the basis of cost reductions of mechanical labour in comparison with the winter ploughing technology. Mechanical labour cost of subsoiling was more than 10% less while the cost of strip tillage was 30% less than in the case of the ploughing technology. The cost of harvesting and transportation was higher in the case of the plough-less technology as a result of the higher yield. In 2012, as a result of the droughty weather the harvesting of maize was carried out with such low grain moisture content, that drying costs did not occur in the case any of the technological variations. In summary, the production costs of the ploughing technology are the highest (325,000 Ft/ha), followed by subsoiling (314,000 Ft/ha), while the lowest costs occurred in the case of strip tillage (306,000 Ft/ha).

Profitability and cost level of every tillage system is favourable. Production is showing a deficit in the case of the ploughing technology if subsidies are not included; however profits can be realised even in this case with subsidies. The highest income can be realised in the case of strip tillage (109,000 Ft/ha). The realised income was influenced mostly by two factors: proportion of mechanical labour is the lowest in strip tillage and the yield of strip tillage significantly exceeded the yields of ploughing and subsoiling technologies.

Although these yields are considered extreme under domestic circumstances, the high maize price (which was a result of the drought) allowed the realisation of profits.

In 2013, there were differences in terms of the cost-income conditions of the involved tillage systems in comparison with the previous year. Favourable economic indexes are characteristic in the case of every tillage method and production was profitable in all three systems even without subsidies. The income realised in the winter ploughing system was the highest (153,000 Ft/ha), followed by the income of subsoiling (137,000 Ft/ha) and strip tillage (129,000 Ft/ha). Production costs have been below market price in all three technologies. Although the cost of mechanical labour was lower in plough-less tillage systems, production cost was still the lowest in the ploughing system. The reason for that: although there was no significant difference amongst the treatments in terms of yield, the harvesting moisture content of plough-less tillage systems exceeded that of ploughing which means a significant extra cost for subsoiling (48,000 Ft/ha) and strip tillage (59,000 Ft/ha). This means 120% extra drying cost for subsoiling and 180% for strip tillage compared to ploughing.

In comparison to the rest of the analysed years, the lowest market price for maize production was recorded in 2014. Winter ploughing technology had the highest production cost (406,000 Ft/ha), while the lowest production cost was recorded in the case of strip tillage (377,000 Ft/ha). Although there was no difference amongst the different systems in terms of the harvesting moisture content of maize in 2014, the difference of drying costs is caused by the yield. The extra revenues caused by the yields in ploughing primary tillage and the lower cost of mechanical labour in plough-less tillage systems resulted in a small difference amongst the incomes of each tillage system. Subsidies had a supplementary income role in 2014, without them income would be around the break-even point in the case of every tillage system.

Table 1: Tillage systems and their important economic indexes in the analysed years (Kenderes, 2012-2014)

	Ploughing			Subsoiling			Strip-tillage		
	2012	**2013**	**2014**	**2012**	**2013**	**2014**	**2012**	**2013**	**2014**
Name	Cost (Ft/ha)								
Material cost	**141 648**	**135 078**	**130 570**	**141 648**	**135 078**	**130 570**	**141 648**	**135 078**	**130 570**
Fertilizer cost	93 519	86 400	81 522	93 519	86 400	81 522	93 519	86 400	81 522
Fall fertilizer	31 200	29 600	28 000	31 200	29 600	28 000	31 200	29 600	28 000
Starter fertilizer	23 800	20 300	18 522	23 800	20 300	18 522	23 800	20 300	18 522
Liquid fertilizer	38 519	36 500	35 000	38 519	36 500	35 000	38 519	36 500	35 000
Seed cost	30 178	30 178	30 178	30 178	30 178	30 178	30 178	30 178	30 178
Plant protection cost	17 951	18 500	18 870	17 951	18 500	18 870	17 951	18 500	18 870
Cost of mechanic labour	**89 103**	**85 787**	**81 897**	**78 154**	**74 630**	**69 613**	**69 488**	**66 401**	**62 806**
Stubble stripping	5 950	5 438	4 876	5 950	5 438	4 876	5 950	5 438	4 876
Stubble treatment	6 200	-	-	6 200	-	-	6 200	-	-
Fertilizer spreading	3 756	3 300	2 826	3 756	3 300	2 826	-	-	-
Primary tillage	20 773	20 105	20 442	15 156	14 380	13 580	16 040	14 970	14 685
Secondary tillage	5 950	5 438	4 876	-	-	-	-	-	-
Seed bed preparation	5 950	5 438	4 876	5 950	5 438	4 876	-	-	-
Sowing	9 300	8 493	7 813	9 300	8 493	7 813	9 300	8 493	7 813
Plant protection	11 295	10 034	8 586	11 295	10 034	8 586	11 295	10 034	8 586
Harvesting	17 295	20 941	20 372	17 295	20 941	20 372	17 295	20 941	20 372
Transportation	2 634	6 600	7 230	3 252	6 606	6 684	3 408	6 525	6 474
Drying	-	21 203	92 148	-	48 638	83 073	-	59 117	83 004
Labor cost	**5 000**	**5 250**	**5 500**	**5 000**	**5 250**	**5 500**	**5 000**	**5 250**	**5 500**
Other cost	**60 000**	**63 000**	**66 000**	**60 000**	**63 000**	**66 000**	**60 000**	**63 000**	**66 000**
Direct cost	**295 751**	**310 318**	**376 115**	**284 802**	**326 596**	**354 756**	**276 136**	**328 846**	**347 880**
Overhead cost	**30 000**	**30 000**	**30 000**	**30 000**	**30 000**	**30 000**	**30 000**	**30 000**	**30 000**
Cost of production	**325 751**	**340 318**	**406 115**	**314 802**	**356 596**	**384 756**	**306 136**	**358 846**	**377 880**
Cost income ratio (%)	2.7%	45.0%	22.4%	26.9%	38.5%	20.8%	35.8%	36.1%	19.8%
Cost level	97%	69%	82%	79%	72%	83%	74%	73%	84%
Prime cost (Ft/kg)	**74.2**	**32.2**	**33.7**	**58.0**	**33.7**	**34.5**	**53.8**	**34.3**	**35.0**
Market price (Ft/t)	63 000	40 500	35 500	63 000	40 500	35 500	63 000	40 500	35 500
Yield (t/ha)	4.39	10.56	12.05	5.42	10.57	11.14	5.68	10.44	10.79
Revenue (Ft/ha)	**276 570**	**427 680**	**427 775**	**341 460**	**428 085**	**395 470**	**357 840**	**422 820**	**383 045**
Subsidies (Ft/ha)	58 000	65 660	69 500	58 000	65 660	69 500	58 000	65 660	69 500
Production value (Ft/ha)	**334 570**	**493 340**	**497 275**	**399 460**	**493 745**	**464 970**	**415 840**	**488 480**	**452 545**
Income (Without subsidies) (Ft/ha)	-49 181	87 362	21 660	26 658	71 489	10 714	51 704	63 974	5 165
Income (Ft/ha)	**8 819**	**153 022**	**91 160**	**84 658**	**137 149**	**80 214**	**109 704**	**129 634**	**74 665**
Break-even point (t/ha)	5.1	8.4	11.4	4.9	8.8	10.8	4.8	8.8	10.6

After the cost-income analysis of each tillage technology the other very important factor – in terms of agricultural machinery investments – is the realisation cost of the technology and the period of return, therefore the investment analysis of the involved tillage technologies has been carried out. The model farm is already in possession of an RTK-equipped power engine and plough, therefore these are not part of the investment costs. The equipment and cost demand of each technology is shown in *Table 2*.

Table 2: Equipment and cost demand of each tillage technology

	Ploughing	**Subsoiling**	**Strip-tillage**
Sowing machine (Ft)	15 000 000	15 000 000	15 000 000
Cultivator (Ft)	11 960 000	11 960 000	11 960 000
Strip tillage equipment (Ft)	-	-	10 000 000
Subsoiler (Ft)	-	4 500 000	-
Total (Ft)	**26 960 000**	**31 460 000**	**36 960 000**

The starting cash-flow of the investment as constituted by the cost of equipment required for the implementation each tillage technology, while the annual cash flow of machinery investment was the half of the income average of the three analysed periods (*Table 3*). The investment was analysed in the case of a 7 year operation cycle in every case.

Table 3: Annual cash-flow of investment financing in the case of each technology

	Ploughing	**Subsoiling**	**Strip-tillage**
Average income (Ft/ha)	42 167	50 337	52 334

Net present value, internal rate of return, profitability index and dynamic return period have been analysed for 6 cultivated area sizes (50 ha, 100 ha, 150 ha, 200 ha, 250 ha, 300 ha). The given area sizes during the 7 year period represent that plot size on which the tillage of maize is carried out with the given primary tillage technology.

The economic indexes related to the implementation of the reduced pass ploughing technology are included by *Table 4*. If only 100 hectares are cultivated with the technology during the seven years, a negative net present value, an internal rate of return which is below the calculative interest rate and a profitability index below 1 indicate that the investment will not return.

Table 4: Main indexes of the investment analysis of the ploughing technology

	NPV	IRR	PI
50 ha	-14 305 594 Ft	-13.13%	0.47
100 ha	-1 651 188 Ft	2.32%	0.94
150 ha	11 003 218 Ft	14.20%	1.41
200 ha	23 657 624 Ft	24.56%	1.88
250 ha	36 312 030 Ft	34.08%	2.35
300 ha	48 966 436 Ft	43.10%	2.82

In the case of an annually cultivated area of 150 hectares or above, every economic index was favourable; however in the case of the 150 ha plot size the investment return might be at risk. In the case of applying the ploughing technology annually on 50 hectares the return period is almost 15 years, therefore the application of the technology is not recommended for this area size. In the case of 150 hectares or above, the investment returns within 7 years (*Figure 15*), however it requires almost 5 years for it to return in the case of 150 hectares. If the size of the annually cultivated area reaches 200 hectares, the investment returns within 4 years, if it reaches 300 it returns within 3 years.

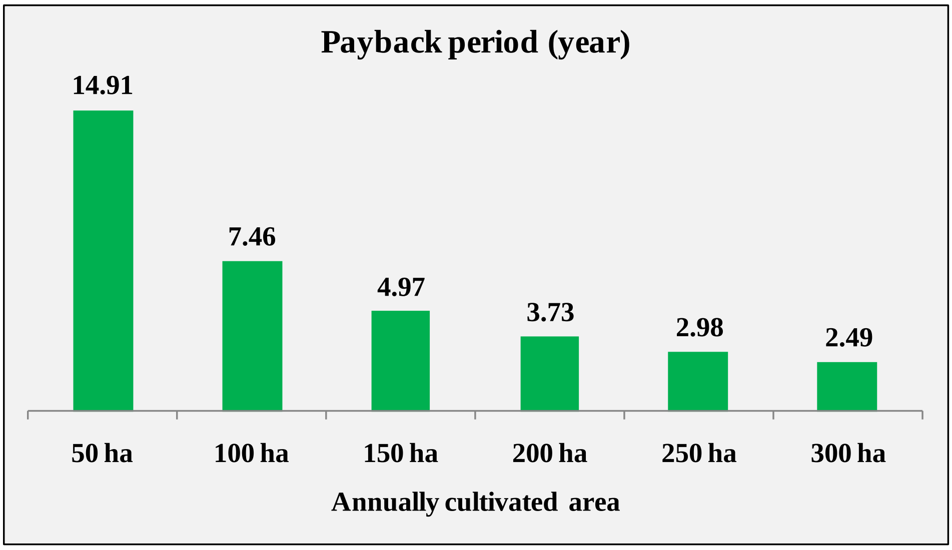


Figure 15 Return periods of ploughing technology depending on the size of the cultivated area

Table 5 includes the indexes of the technology based on the subsoiler. Similarly to the ploughing technology, the application of this variation on 100 hectares annually does not ensure the return of the investment. If the technology can be applied on 150 hectares or more, the indexes of economic operation will be favourable in every scenario.

Table 5: Main indexes of the investment analysis of the subsoiling technology

	NPV	IRR	PI
50 ha	-16 353 767 Ft	-12.70%	0.48
100 ha	-1 247 534 Ft	2.92%	0.96
150 ha	13 858 699 Ft	14.95%	1.44
200 ha	28 964 931 Ft	25.46%	1.92
250 ha	44 071 164 Ft	35.14%	2.40
300 ha	59 177 397 Ft	44.32%	2.88

In terms of return time, subsoiling technology can be characterised similarly to the ploughing technology. Its application on 50 hectares can calculate with a return above 14 years, while on 300 hectares it returns within 3 years (*Figure 16*). Amongst the three analysed technologies the return values of subsoiling are slightly the most favourable.

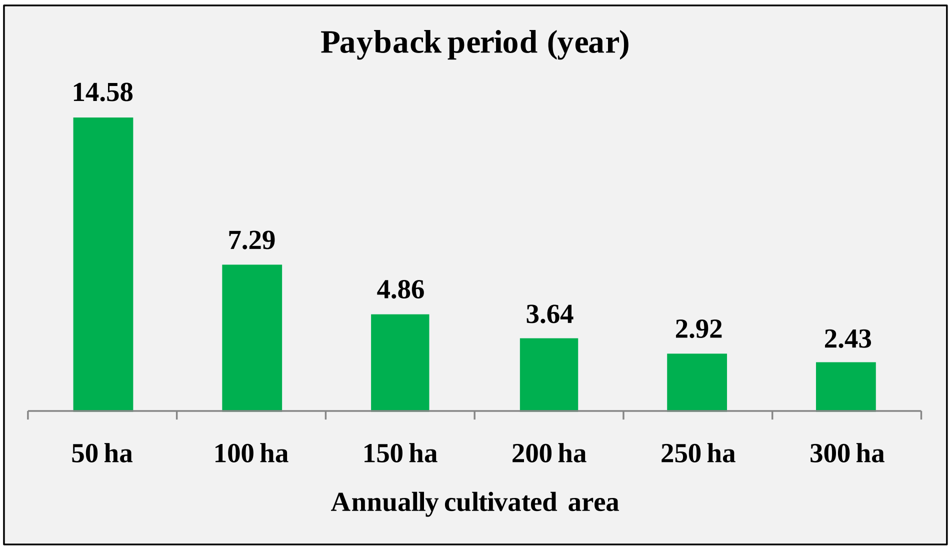


Figure 16 Return periods of subsoiling technology depending on the size of the cultivated area

Table 6 includes the indexes required for the evaluation of the return-analysis of strip tillage. In the case of operating it annually on 100 hectares or below, strip tillage technology is not profitable.

Table 6: Main indexes of the investment analysis of the strip tillage technology

	NPV	IRR	PI
50 ha	-21 254 449 Ft	-14.99%	0.42
100 ha	-5 548 899 Ft	-0.22%	0.85
150 ha	10 156 652 Ft	11.03%	1.27
200 ha	25 862 202 Ft	20.76%	1.70
250 ha	41 567 753 Ft	29.65%	2.12
300 ha	57 273 303 Ft	38.03%	2.55

Its application on 150 hectares or more results in the return of the technology investment (*Figure 17*). When applied on 100 hectares or less, return time exceeds the planned period of the investment (7 years), therefore the application of the technology is not recommended on that area size. When applying the technology on 200 hectares, it will return at almost half of the planned return period of the investment.

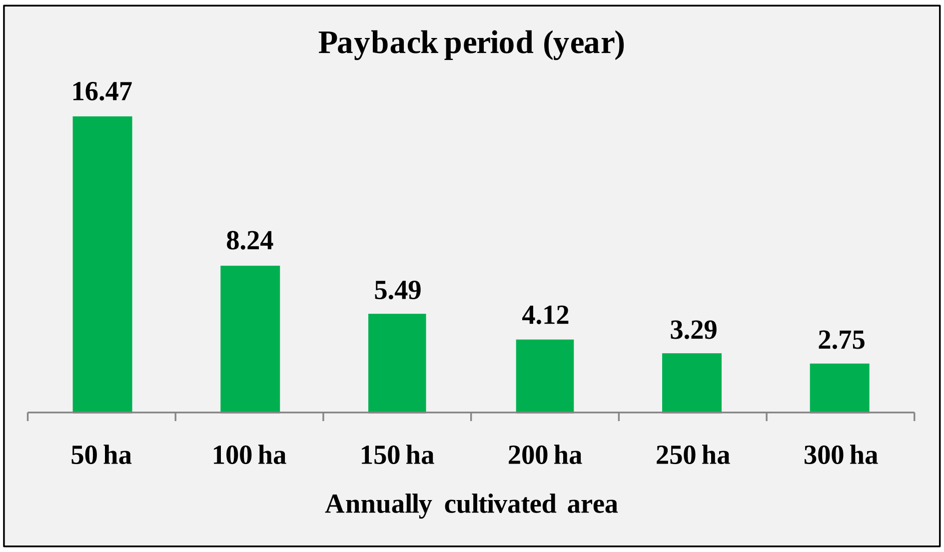


Figure 17 Return periods of strip tillage technology depending on the size of the cultivated area

4. NEW SCIENTIFIC RESULTS OF THE THESIS

1. I found that in the case of the TDR-based (Time Domain Reflectometry) measurement method during soil moisture content measurement and the determination of the minimum number of measurements, estimation error is higher if calculations are based on return time than if they are based on volume percentage moisture content.
2. I verified the moisture preserving role of plough-less (strip-tillage and subsoiling) tillage systems. Depending on the year, there was 10-50% higher soil moisture content of the 0-20 cm soil layer of plough-less systems.
3. I verified through soil penetration resistance measurement that both plough-less and ploughing-based tillage systems are capable of providing optimal, compaction-free soil conditions for maize. There was no soil penetration resistance value exceeding 3 MPa with the analysed layer.
4. I introduced – through a soil penetration resistance profile analysis – the effect of tillage equipment applied in the trial on soil conditions.
5. I verified the cost-effectiveness of plough-less tillage systems (strip-tillage and subsoiling) in comparison with ploughing primary tillage. The costs of mechanic labour was 15-30% lower in the plough-less tillage systems, than the costs of winter ploughing technology.
6. I proved that the extra drying costs – caused by higher harvested grain moisture content – might unfavourably affect the cost-effectiveness of strip tillage. The drying costs of plough-less technologies can be 20-270% higher comparison to the conventional tillage.
7. By means of complex agronomic and economic analyses I verified the applicability of strip tillage production technology of maize on meadow chernozem soil under Hungarian production circumstances.

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List of publications related to the dissertation

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