**Theses of Doctoral (PhD) Dissertation**

# RESEARCH AND DEVELOPMENT OF PRECISION FARMING TECHNICAL AND AGRICULTURAL TECHNOLOGY

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# 1. INTRODUCTION

All technology elements must provide and guarantee a perfect and rapid crop emergence in maize production after the previous crop. It is important to create and maintain a proper physical and biological condition of the soil. Farmers should aim to combine the needs of the crop with sustainable and cost-effective technological requirements.

A key factor in successful maize production is water, and water availability is important for the crop from sowing to the end of the growing season. This is a high requirement in the Hungarian climate. Rainfall often does not fall when and in the amounts that maize needs.

The farmer has to manage with water-saving tillage techniques to ensure that rainfall infiltrates into the soil, does not evaporate or cause damage (wind and water erosion). It is important to choose and use the right tillage system to create a healthy soil structure. This condition is maintained over the long term, it is at a minimum during the growing season, it is able to store the rainfall, it provides suitable habitat for plant roots and soil biological communities.

The conscious maize grower has all the tools and possibilities to create the right soil conditions. The use of tillage technologies that achieve the objectives is important, it is used in a technological system to ensure satisfactory results. However, all tillage systems have advantages and disadvantages. The farmer must decide after the summary. Farmers must choose technological solutions for crop production that reduce the negative effects of the disadvantages while preserving the advantages.

Precision planting is an important technological aspect in maize cultivation. In the area of precision planting technology, technical solutions increasing the quality of precise, site-specific application of inputs for planting. Precision seed placement systems have received less focus. My research focuses on this topic. The basis of my study is that I have developed a technical specification for use on national seed planters. With this, the elements responsible for the seed placement and the optimum germination state of the seed are automatically adjusted during the sowing process, taking into account the soil conditions, based on measured data.

The seed drill works in response to the heterogeneity of the field. Using this technology eliminates the need for a large number of aggressive tillage practices that degrade soil biology and destroy soil life through soil structure degradation and moisture loss. It is sufficient to follow the principle of necessary and sufficiency, as this planting technique does not require a garden seedbed. However, it does allow a homogeneous planting depth and an optimum soil structure for germination.

During sowing, there is an important fact for every maize grower. You can only plant well once in a growing season. Technological errors made during planting are reflected in the number of seedlings and their emergence dynamics. Incorrect planting cannot be remedied later by any input inputs or technological operations, and its effect lasts until the end of the growing season and determines the success of the crop. In my dissertation, I analyse these factors in a precision maize production system.

Main objectives of my research:

- In my research, I decided to compare four different tillage systems for maize production. In particular, the study of the parameters that can be decisive for the homogeneous development of the crop, the emergence and the development of the population. These are the state of soil compaction, the water retention capacity of the soil, the surface coverage of the stem residue and the soil temperature conditions at the planting depth.
- My aim is to apply different planting systems in different tillage systems and to measure their effects on maize germination, to measure differences in germination dynamics.
- My goal is also to find correlations between the time of emergence and crop development and yield.
- I want to measure the effect of different treatments on the biomass product value of each experimental area.
- My aim is to measure the time to emergence and the stalk diameter of maize.
- My goal is to study the relationship between the time of emergence and the individual product of the plants.
- My aim is to demonstrate the impact of different planting quality improvement systems on yields
- My aim is to develop a system for improving the yield of maize grown under no-rotation tillage systems that can be effectively applied in field practice.

## 2. MATERIALS AND METHODS

### 2.1 Experimental Area

The experiment was conducted in the eastern region of Hungary at Nádudvar (47°25'49.3 "N 21°12'33.5 "E). Four different tillage systems will be applied in the pilot area from autumn 2016. The area is 25 ha, divided into 5 separate plots, where different crop rotations are carried out, including maize, which is the basis of my study. For the PhD thesis, the periods studied were 2020, 2021 and 2023. The maize plant was established on a 4.5 ha plot. The experimental area was further divided into 4 plots and different tillage systems were applied in these plots (Figure 1).

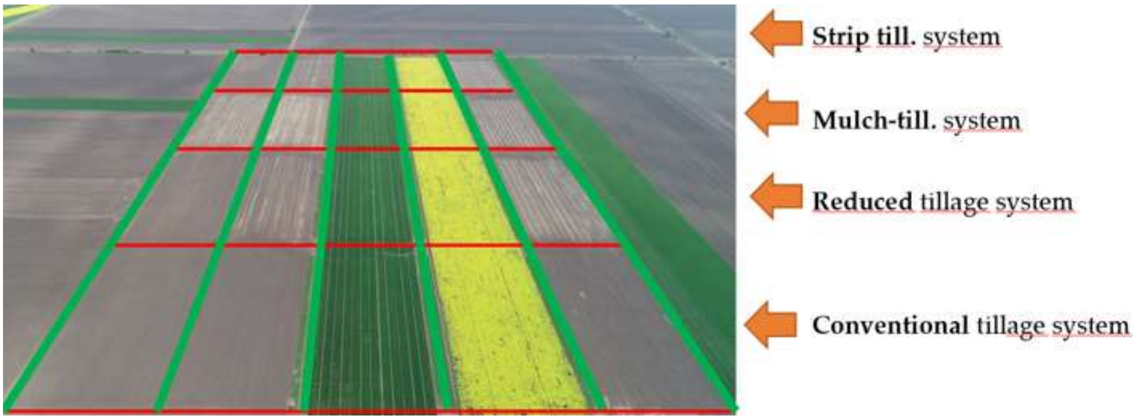



**Figure 1.** Layout of the experimental site, Nádudvar

### 2.2 Soil tillage settings of the location

In the first area we used a conventional rotational tillage system, where the plough is the basic tillage machine, the ploughing depth is 30 cm and there is no residual stalk on the surface. In the second part of the area, a reduced tillage system without rotation tillage. Here, the basic tillage equipment was a medium-depth cultivator with a mixing effect. It is characterized by a maximum of 15% of stem residues remaining on the surface. In the third area we used the mulch tillage system with straight knife soil looseners, in this case the entire surface was loosened to a maximum depth of 30 cm. Then, after the basic tillage technology, a stem residue cover of over 30% remains.

In the fourth area, we used the strip-tillage system, with strip-tillage as the basic cultivation method

## 2.3 Demonstration of an experimental planter

The planter used in the planting was equipped with 3 different systems of seed carriage loading. For the first setup, a mechanical system with a tension spring. The second setup was a compression spring system. In the third set-up, I installed a precision seed drill adjustment system on the planter. In this case, a measuring sensor was inserted in the depth limiting wheel adjustment mechanism next to the seed coulters, which measures the contact with the soil for each seed unit separately. In addition to the measuring system, I have also integrated a control and manipulation device, whereby a hydraulic working cylinder can be used to apply different loads to each seed row according to the measured condition, i.e. the soil quality.

I made in 2023 further modification on the planter was done on the seed furrow closing system. At that time, the original seed drill's seed closing system was used. In this case, the double closing wheels run behind the opening discs and cover the seed furrow.

For the second technical design, the original closing system has been replaced and a Precision Planting Furrow force closing system is fitted. The solution includes several changes. The seed trenches are inserted by a pair of angled discs. Which pushes the walls of the seed trench into the seed. In the following, 2 wider closing wheels than in the original solution will clog the trench. The load force required to operate the unit is applied by a pneumatic working cylinder. The force of contact of the unit with the ground is measured by a force sensor. Based on the measured actual contact with the ground, the load force is autonomously controlled by the central control system on a line-by-line basis.

## 2.4 Treatments in 2020 and 2021:

1, Mechanical tension spring: 40 kg/ with load on the row unit + mechanical closing adjustment

2, Mechanical tension spring: 80 kg/ with load on the row unit + mechanical closing adjustment

3, Compression spring: 57 kg / row unit load + mechanical adjustment closing

4, Compression spring: 113 kg/ wagon load + mechanical locking

5, Precision seed row unit load system: variable load based on the measured results of the soil parameters with hydraulic automatic adjustment of the seed wagon force per row unit + mechanical adjustment of the closing

### 2.5 Treatments in 2023

1, Mechanical tension spring: 40 kg/ with load on the row unit + mechanical closing adjustment

2, Mechanical tension spring: 80 kg/ with load on the row unit + mechanical closing adjustment

3, Compression spring: 57 kg / row unit load + mechanical adjustment closing

4, Compression spring: 113 kg/ wagon load + mechanical locking

5, Precision seed row unit load system: variable load based on the measured results of the soil parameters with hydraulic automatic adjustment of the seed wagon force per row unit + mechanical adjustment of the closing

6, Precision downforce load system + Precision seed closing system: variable load based on the measured results of the soil parameters by automatic adjustment of the pneumatic pressure cylinder on the closing wheels.

### 2.6 Test methods

#### 2.6.1 Measuring soil temperature

Soil temperature and soil moisture were measured in the soil of plots under different tillage systems. The temperature sensors were measured at a depth of 5 cm in the planting depth along the line of the planted row.

#### 2.6.2 Penetration resistance of soil

To characterize the soil looseness, I measured the soil penetration resistance. This measurement measured to a depth of 70 cm and the meter saved the results in 1 cm increments. The measuring device complied with ASAE S313.3. The gauge measured the penetration force in N dimensions, which I later converted to MPa during the analysis.

#### 2.6.3 Measurement of surface coverage

The surface cover of stem residue in different tillage systems at different times was determined. As a first step of this measurement, I surveyed the area with a drone equipped with a multispectral camera. Measurements were taken with a DGI Phantom 4 multispectral drone every 10 days during the 3 different growing seasons. The camera on board the drone included one RGB camera and five multispectral cameras covering the blue, green, red edge and near-infrared spectra with a resolution of 2 MPix. The resulting images were analysed using ArcGis geospatial software. The result was a surface coverage %.

### 2.6.4 Measurement of plant germination dynamics

After planting I did a germination survey. In a homogeneous area of each treatment, sample plots were measured in 4 replicates in a randomized design on experimental plots sown with different systems. Each sample field was 16m long and contained 4 maize rows. I marked first emerged corn in these sample plots by sticking a coloured stick into the soil next to the emerged plant. I used differently coloured marking sticks to identify individuals that emerged on each day, and the same coloured sticks to identify individuals that emerged on that day. The marking was done in the morning of each day at the same time. I continued this series of measurements for 6 days. The proportion of individuals marked by colour code was recorded.

The marker sticks kept undamaged on the growing plants all the growing season. These were used as a basis for the physiological parameters of the developing plants at different stages of phenology and then as a basis for the study of the yield-forming elements.

### 2.6.5 Stem diameter measurement based on plant emergence days

Above the lowest node, I measured uniformly with a caliper the plants grouped with different emergence markers. The time of measurement was after biological maturation, when the plant is no more growing. I measured 10 plants of each emergence marker colour per tillage system. The result was given in mm dimension.

### 2.6.6 NDVI measurement

The most frequently used measure of plant biomass in vegetation is the NDVI index (Araus et al. 2001). Measurements were made every 10 days during 3 different seasons using a DGI Phantom 4 multispectral drone. The camera on board the drone included one RGB camera and five multispectral cameras covering the blue, green, red edge and near-infrared spectra with a resolution of 2 MPix. The data were merged and processed using Qgis software.

### 2.6.7 Individual potential yield measurement based on the plant's days to emergence

The corn cobs grown on the marked plants were harvested individually, separated according to the colour coding, and collected in groups according to the colour code. This was done at the end of the growing season after biological ripening in the first part of October. I collected 40 samples from each of the four replicates, separated by treatment and from each tillage system, in each of the four years under study. The samples were then sent to the laboratory of the University of Debrecen, where the physical length, weight and diameter of each maize cob were measured separately. Maize cob length was measured with a tape measure and cob diameter with a caliper by determining the diameter of the middle part of the cob. Corn cobs separated by colour code were.

I used a Haldrup individual potential measuring machine to pick corn kernels one by one and then quantified the yield parameters formed on a corn cob. The individual potential measuring machine measured the number of grains per cob and the weight per thousand kernels.

### 2.6.8 Measurement of content parameters based on the plant's days to emergence

I packaged the crushed samples separately. I measured them separately and determined the content parameters using a Perten DA7250 (PerkinElmer Inc., Waltham, MA, USA). The starch, grain moisture, oil and protein content of the samples were determined.

### 2.6.9 Measuring the yield of treated plots

Individual yield measurements of the treated plots were also made. As each treatment was 910 m², it was possible to measure the yield with a harvester equipped. The machine is a John Deere S670 and the position coordinates linked to the crop data are RTK accurate (+/- 2.5 cm). I have isolated about 50 measured yields from one treatment.

### 2.6.10 Statistical analysis

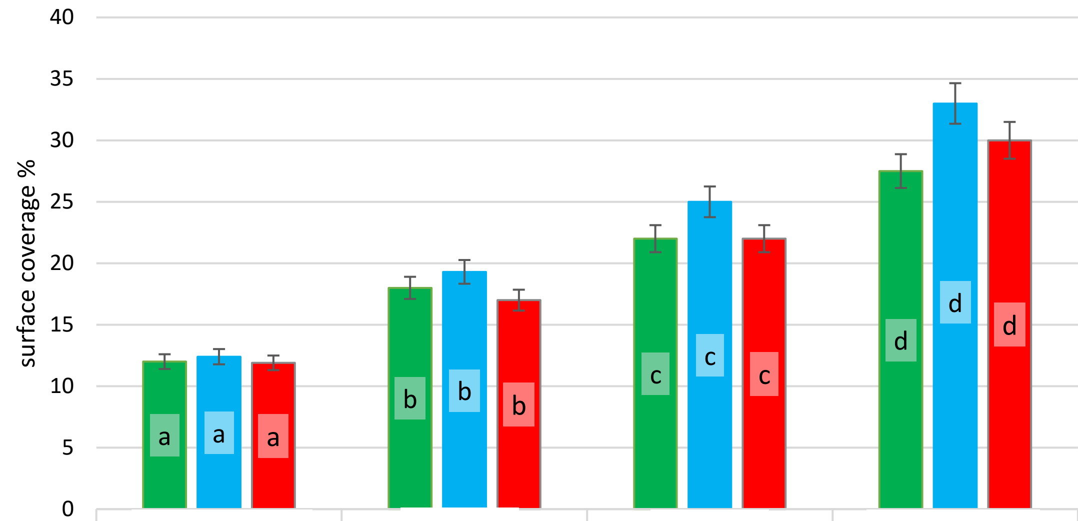
Microsoft Excel 365 was used to summarise and process the data. For statistical analyses I used SPSS 25. Analyses were conducted according to international and national methodologies (Berzsenyi, 2010). I primarily performed normality tests on the data using Kolmogorov Smirnov test. I determined the correlations between each factor using regression analysis. I explored the relationships between treatments using analysis of variance. Then I used One way Anova and additionally General Linear model. I tested for individual covariance using Duncan's test.

## 3. RESULTS

At my experimental site (as in most areas of our country), rainfall often does not fall when and in the amounts that the maize needs. I measured the amount of precipitation falling before the growing season and during the growing season in the years under study, and based on these, I examined different seasons. The use of precipitation depends on how much of the precipitation can infiltrate into the soil and how much evaporates. I have confirmed in the studied years: the conventional tillage system with rotation has significantly different soil compaction in both May and August compared to no-rotation tillage. Non-rotated tillage systems had a statistically significant looser structure at the beginning of the growing season, with a compaction not exceeding 5 MPa, and no hard compacted layer exceeding 7 MPa was found in their structure.

Based on my research results, I found that the used tillage system changed the physical structure of the soil and affected its water balance in the long term. The results of my studies confirm the similar findings of several other studies that tillage practices affect soil physical properties in different soil layers (Alakukku 1998, Stelluti 1998, Gao 2016). My further measurements confirmed that the water holding capacity of the soils differed between the studied tillage systems. The conventional rotation tillage system had significantly less (as little as 25%) water available to plants during the growing season than the non-rotation tillage system. I have demonstrated through measurements and statistical analysis that different tillage systems have a statistically significant effect on soil water retention. My results are also supported by studies of other researchers, because the tillage system determines the pore size distribution of the soil, which influences the infiltration and retention of water (Hillel, 1998, Kutílek and Nielsen, 1994).

The use different tillage systems will result in different stem residue coverage at planting and post-planting. The results show significant differences in the averages of the percentages of cover in all three years (Figure 2). The statistical analysis compares the results of the measurements taken in the pre-sowing period after seedbed preparation in each year (means with the same letter are not different at the p=5% probability level).




| | Conventional | Reduced | Mulch | Strip till |
|---|---|---|---|---|
| 2020 | 12 | 18 | 22 | 27,5 |
| 2021 | 12,4 | 19,3 | 25 | 33 |
| 2023 | 11,9 | 17 | 22 | 30 |

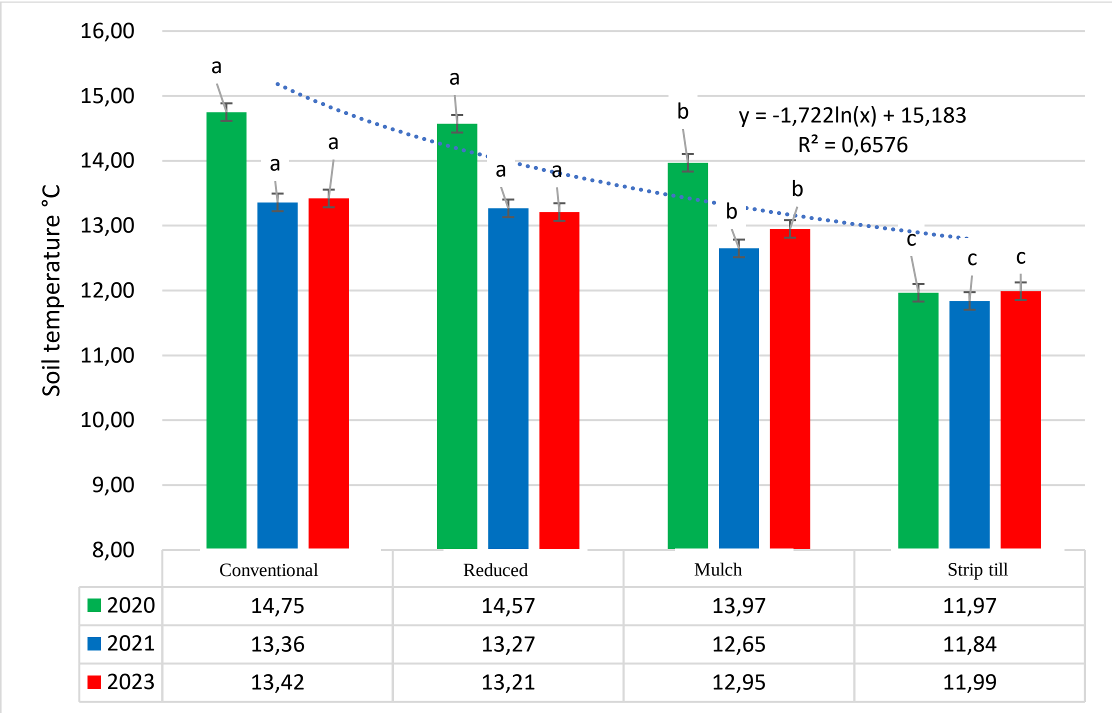
Means with the same letter are not different at the P=0.05 probability level

Figure 2: Average ground cover of samples of different tillage systems after seedbed preparation in three seasons

The results of my study showed that the surface cover of the treated plots was 12%, 12.4% and 11.9% stem residue cover after conventional cultivation, while the average surface cover of the soil protection strip system in the pre-sowing stage was almost three times higher. My measurements are supported by similar results from several literature (Hammel, 1989; Ferreras et al, 2000; Kok, 1996).

In my research, I also studied the effects of different technical solutions of planting technology on the germination dynamics of the emerging crop. In the first two seasons I studied commonly used load force systems. I studied this system in different settings. I also used a precision-sensing system that autonomously makes adjustments based on measured data and soil conditions. From an agro-technical point of view, there is a difference between the different seeding treatments in terms of the precision and homogeneity of the planting depth of the planter and the management of the seed furrows during planting. I have extended in 2023 the planting variation tested in the previous two seasons by a sixth.

I also tested precision furrow closing during planting. I compared it with the other treatments. My research has demonstrated that precision seeding technology systems that improve the quality of planting under different tillage conditions, they could statistically improve the germination dynamics of maize stands. Significant emergence uniformity results were measured with precision systems, especially in the 2023 season, when both seed row unit loading and closing were based on precision interventions. My measurements have shown that precision systems result in more uniform crop growth over a shorter time interval. My measurements show that this effect is stronger in the colder cultivations, with temperatures up to 2.78°C lower and 33% ground cover (Figure 3).




| | Conventional | Reduced | Mulch | Strip till |
|---|---|---|---|---|
| 2020 | 14,75 | 14,57 | 13,97 | 11,97 |
| 2021 | 13,36 | 13,27 | 12,65 | 11,84 |
| 2023 | 13,42 | 13,21 | 12,95 | 11,99 |

Means with the same letter are not different at the P=0.05 probability level

Figure 3. Average soil temperatures in planting depth from planting to emergence

I marked the emerging maize plants by sticking a coloured stick into the soil next to the emerging plant. I used different coloured marker sticks to identify individuals that emerged on different days, and the same coloured sticks to identify individuals that emerged on the same day. The markings remained next to the plants throughout the growing season. Using this marking, I carried out tests during the growing season to prove that there is a correlation between stem diameter and days to emergence. With my measurements, I was able to demonstrate that plants that emerged on the first and second days developed stems with a stalk diameter that was significantly larger (P=0.05) than those that emerged on later days. Yields are based on the production of the individual plant. Separate analyses of individually harvested maize cob samples from the plants marked at emergence were carried out for their physical and content parameters. Based on my tests, I found a strong correlation between individual cob weight and days to emergence. This correlation was confirmed in all three years (Figure 4).

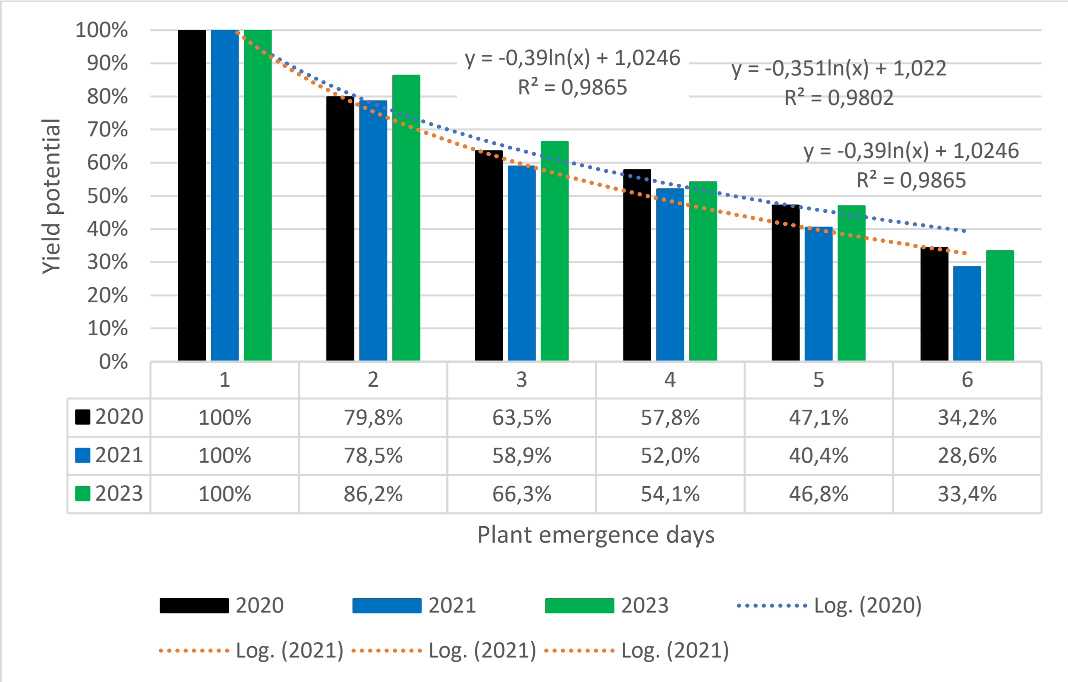



Figure 4: Variation of yield potential depending days to plant emergence

I could not prove a correlation between the two parameters with respect to plant emergence date and maize cob diameter. I did find a statistical correlation between maize cob length and days to emergence, i.e. the earlier a plant emerged, the longer the cob developed (Table 1). There was no statistically proven correlation between the content parameters and the days of emergence. Based on my results, it has been confirmed that the use of precision planter loading and closing systems makes a significant positive contribution to this goal, depending on the type of tillage.

By the second day, the plants have already lost between 13.8% and 21.5% of the yield. Plants that emerged on the third day yielded between 33.7% and 41.1% less. Plants that emerged on the fourth day had yield losses ranging from 43% to 48% compared to those that emerged on the first day. The fifth day of emergence resulted in yield reductions of between 52.9% and 59.6%, and the sixth day of emergence resulted in yield reductions of between 65.8% and 71%.

Table 1: Relationship between plant emergence days and maize cob length in three seasons

| emergence days | maize cob length (mm) | | | | | |
|---|---|---|---|---|---|---|
| | 2020 | SzD5* | 2021 | SzD5* | 2023 | SzD5* |
| 1 | 184,76 | a | 147,80 | a | 159,00 | a |
| 2 | 166,76 | b | 133,40 | b | 148,00 | b |
| 3 | 151,11 | c | 120,89 | c | 137,00 | c |
| 4 | 140,89 | d | 112,71 | c | 131,60 | c |
| 5 | 128,12 | e | 102,49 | c | 105,30 | d |
| 6 | 106,53 | f | 85,22 | d | 100,50 | d |

* Significant difference: means with the same letter do not differ at the P=0.05 probability level

I completed my study by analysing the harvested yield of the treatments. My results showed that mechanical systems were lower than precision systems in terms of yield (Table 2).

Table 2: Planting systems and yields in the tillage systems in 2023

| Applied planting system | Dry grain yield t/ha 14% | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Conventional | SzD5* | Reduce | SzD5* | Mulch | SzD5* | Strip till | SzD5* |
| Tension spring 40 kg | 13,89 | a | 13,33 | a | 13,57 | a | 14,12 | a |
| Tension spring 80 kg | 13,92 | a | 13,51 | b | 13,63 | a | 14,21 | a |
| Pressure spring57 kg | 14,05 | ab | 13,60 | b | 14,18 | b | 14,25 | ab |
| Pressure spring113 kg | 14,06 | ab | 13,63 | b | 14,25 | b | 14,42 | b |
| Precision depth control | 14,21 | b | 13,85 | c | 14,61 | c | 14,68 | c |
| Precision depth control + precision closing | 14,73 | c | 14,15 | d | 14,80 | c | 15,01 | d |

* Significant difference: means with the same letter do not differ at the P=0.05 probability level

This can be illustrated by my results presented earlier. The poorer germination dynamics results measured with the mechanical planter loading systems were manifested in the reduction of the individual yield in the later years. This effect was measurable for the harvested total maize population in terms of yield.

## 4. NEW SCIENTIFIC RESULTS

1. I have demonstrated that there were statistically significant differences in the water holding capacity of soils in the tillage systems under study. The conventional tillage system with rotation had significantly less water available to plants during the growing season ( 12.2 - 27.7 V/V % at 35 cm depth ) than the no-rotation tillage system ( 14.4 - 32.6 V/V % at 35 cm depth ).

2. I have confirmed that significant differences in soil temperature conditions from planting depth to emergence were observed in the four tillage systems. The length of the period below the base temperature of 10 ºC was, depending on the season, warmest in the conventional tillage system for 22-27 hours, 26-32 hours in the reduced tillage system, 29-38 hours in the conservation tillage system and coldest in the strip tillage system for 32-41 hours. I have demonstrated that differences in soil temperature in the different tillage systems caused a delay in germination of up to 4 days for the same hybrid.

3. I have demonstrated that precision planting systems can improve germination dynamics. Significant differences were measured between the effect of conventional mechanical planter loading systems and precision systems on emergence dynamics. This effect is particularly strong in unfavourable cropping years, leaving more ground cover. In the worst treatment with a mechanical drill loading system, 25% of the plants germinate on the first day of emergence, compared to 84% in the best treatment with a precision drill quality improvement system.

4. My research results have demonstrated that there is a strong correlation between the day of emergence and the individual product of maize. It is $r^2$=78% in 2020, $r^2$=81,5% in 2021 and $r^2$=82% in 2023. Based on my results, the plants that emerged on the first day of emergence had the highest yield. In comparison, the plants that emerged on the second day had a yield loss of between 13.8% and 21.5% depending on the year. The third day plants yielded between 33.7% and 41.1% less. Crops that emerged on the

fourth day had yield losses of 43% to 48% compared to those that emerged on the first day. The fifth day of emergence resulted in yield losses between 52.9% and 59.6%, and the sixth day of emergence in yield losses between 65.8% and 71%.

## 5. PRACTICAL USE OF RESULTS

1. For maize farms growing maize on the domestic medium-hardy chernozem soil, I recommend a switch from conventional rotational tillage to non-rotational tillage systems, which will result in a more optimal soil structure. Mulch till and strip tillage systems can create the ideal physical conditions for maize growth without soil degradation.

2. My measurements have demonstrated that more moisture is available in non-rotated cultivation systems compared to conventional cultivation systems. With non-rotated systems, greater yield reliability can be achieved.

3. Based on my results, I have demonstrated that it is possible to create a stem residue soil cover of more than 30% by the maize planting period, which protects soil structure and water resources.

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# 7. PUBLICATIONS RELATED TO THE DISSERTATION

DEBRECENI EGYETEM
EGYETEMI ÉS NEMZETI KÖNYVTÁR
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Tárgy: PhD Publikációs Lista

Jelölt: Sojnóczki István
Doktori Iskola: Kerpely Kálmán Doktori Iskola
MTMT azonosító: 10073908

### A PhD értekezés alapjául szolgáló közlemények

Magyar nyelvű tudományos közlemények hazai folyóiratban (12)

1. **Sojnóczki, I.**, Nagy, J., Kecskés, I.: A kukorica (Zea mays L.) kelési dinamikának a termésre gyakorolt hatása.
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### További közlemények

Magyar nyelvű tudományos közlemények hazai folyóiratban (1)

18. Hadászi, L., Illés, Á., Bojtor, C., **Sojnóczki, I.**, Nagy, J.: A kukorica hibridek smart paramétereinek elemzése = Analysing the smart parameters of maize hybrids. *Növénytermelés. 72* (2), 21-36, 2023. ISSN: 0546-8191.

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

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

A DEENK a Jelölt által az iDEa Tudóstérbe feltöltött adatok bibliográfiai és tudománymetriai ellenőrzését a tudományos adatbázisok és a Journal Citation Reports Impact Factor lista alapján elvégezte.

Debrecen, 2024.07.02.