# EFFECT OF DIFFERENT TILLAGE METHODS ON THE SOIL RESISTANCE AND THE PHYSIOLOGICAL PARAMETERS OF MAIZE

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***Abstract.*** *The aim of this research was how minimum tillage differs from conventional tillage in an irrigated system? The experiment was made in the area of Szarvas (Hungary) in 2022-2023. The type of the soil was chernozem, slightly acidic and with a medium content of humus. The crop culture was early maturing maize (FAO 350). The weather throughout the year was very dry with low amount of rain so this reduced the yield. We separated irrigated, 2x and 4x irrigated parcels and used minimum and conventional tillage. The irrigated treatments were watered four times. During the Leaf Area Index measurement, we did not find any significant difference between tillage types, but between irrigations the research showed significant changes. Non-irrigated LAI data was around 1,05 $m^2/m^2$, in the irrigated parcel it was ~2,54 $m^2/m^2$. The same result could be obtained from the Soil Plant Analysis Development (SPAD). The lowest value was in the minimum tillage (unirrigated) parcel, 46,89. Anyway the highest value was in the minimum tillage (irrigated) parcel, 58,83. In the case of yield the maize reached maximum of 6,88 tonnes/hectare in irrigated treatments. Yields ranged from 3 to 4 t/ha in the parcels where we did not irrigate. Last but not least the soil resistance represented us that in the minimum-tillage parcels, the resistance was much higher in than the conventional tillage at the same depth. So, summarizing my measurements, I can conclude that irrigation has a positive effect on maize in many respects. From the comparison of the tillages, I concluded that there was no significant difference between minimum and conventional tillage in most cases. However, min-till is economically much reasonable than conventional tillage. Therefore, the use of minimum-tillage in maize cultivation is recommended.*

***Keywords****: maize, minimum tillage, conventional tillage, irrigation, yield*

## INTRODUCTION

In the crop production the maize *(Zea mays L.)* has great impact, because of the versatility of use. In this way, maize is becoming one of the three most important cereal crops all over the word (Futó and Bencze, 2023). Maize requires a significant input of nutrients and it is particularly demanding on the soil (Galindo et al., 2024). Tillage is an essential component of agricultural production. Tillage represents essential aspect of maize production within the wider context of agriculture (Cheţan et al., 2022). It is also evident that climate change is affecting maize production in Hungary (Ssemugenze et al., 2024). The extreme weather conditions will result in the occurrence of drought or inland flooding with more frequency. (Tarnawa et al., 2023). Among these potential problems, irrigation could help mitigate the effects of drought and it can also increase yields. (Daryanto et al., 2016; Széles et al., 2024). And the new tillage systems could be beneficial to soil life and fertility, promoting better water retention and nutrient availability (Chețan et al., 2023).

Irrigation plays a vital role in maize grain production. According to Buttinelli et al. (2024) irrigation is important to make maize economically viable. They found that the analysis of the coefficients indicates a notable positive correlation between water and fertilizers. Conversely, an inverse relationship was found between water and pesticides. The coefficients linked to weather variables, such as temperature and rainfall, did not show statistical significance.

The climate change and rising temperatures will lead to increased water scarcity, which will have a detrimental impact on maize yield in suitable climates. However, irrigation can help to relieves this problem (Król-Badziak et al., 2024).

So, irrigation helps mitigate the adverse effects of climate change by providing necessary water during critical growth stages, thus stabilizing yields and improving productivity under changing climatic conditions. The implementation of an appropriate irrigation management strategy, in terms of both amount and frequency, has the potential to enhance the economic viability of maize production while simultaneously reducing the costs associated with it (Gao et al., 2021). Maize yields increased by an average of 18.7% with rain-fed irrigation.(Kresovic et al., 2014) However, it might be more beneficial to consider advanced tillage methods as a way of improving moisture conservation in the soil. The conservation tillage practices have the potential to enhance the soil quality, water management, and crop yields by improving root penetration, reducing erosion, and increasing water infiltration. (Box and Langdale, 1984) According to Orfanou et al. (2019) the conventional tillage method results in higher yields than conservation tillage. However, the differences between the two are not significant, suggesting that conservation tillage may offer a viable alternative for achieving acceptable yield results while also preserving water. (Orfanou et al., 2019)

The highest amount of yield can be found in conventional tillages, but this method consumes the most amount of fuel and irrigation water. For this reason, the minimum tillage method could be a better option because it consumes the least amount of fuel and water, with a bit lower yield. (Sayed et al., 2020)

The tillage management strategies caused different results between the traditional conventional and new conventional tillage rotations. As a study, the sub-soiling and no-till methods reduced soil compaction and had a positive effect on maize chlorophyll content compared to the traditional treatment. In the same way the chlorophyll content in the early growth period increased by 31.8% and 24.6% in the innovative treatments. And the soil compaction value was the maximum at 20 cm in the traditional treatment (Liu et al., 2023) The SPAD value is observed to be higher in minimum tillage than in conventional tillage, indicating that the former method may be more effective in terms of production (Edalat et al., 2019). However, the use of tillage systems had no significant impact on chlorophyll content (SPAD) across different nitrogen rates (Liu and Wiatrak, 2012). The interactions between hybrid and tillage were not found to be statistically significant for SPAD values measured at the late phenological stage of maize (Shinoto et al., 2020).

## MATERIAL AND METHODS

The experiments were conducted in the area of Szarvas, Hungary (Békés County) between 2022 and 2023 at the Hungarian University of Agriculture and Life Sciences. The weather in the two years of the experiment was very different. While the first (2022) was a dry, hot and drought-prone year, the second (2023) was a wetter and milder, but not drought-free year. Although in 2022 not, but in 2023, with irrigation, great results were achieved in maize cultivation.

In 2022 from June to August, approximately 75 mm of precipitation was recorded, with the majority of this amount occurring over a period of 2-4 days across the three-month period. Maize, on the other hand, requires the majority of its water from early July to late August, specifically during generative phenology. This has already resulted in a significant reduction in yields. Additionally, these months also saw the highest temperatures, which were challenging for the plant to tolerate even under irrigated conditions. Consequently, the combination of low rainfall and high temperatures during the growing season led to a reduction in yield averages, even with irrigation. In 2023, the weather conditions were considerably more favourable, with a more even distribution of rainfall throughout the summer months. Thus, overall, neither drought nor atmospheric drought had a significant impact on crop averages. In summary, in 2023, excellent results could be achieved in maize crops with irrigation whereas in 2022 less. *(Table 1)*

*Table 1*

Precipitation data 01.01.2022. - 30.09.2023. (Szarvas)

| *Data of rainfall 01-12. 2022. Szarvas* | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Months** | **Jan.** | **Febr.** | **Marc.** | **Apr.** | **Maj.** | **Jun.** | **July.** | **Aug.** | **Sept.** | **Okt.** | **Nov.** | **Dec.** | **SUM** |
| Rainfall (mm) | 14,5 | 4,8 | 7,8 | 42,1 | 13 | 21,3 | 20,8 | 33,4 | 57,7 | 2,5 | 38 | 87,6 | 343,5 |
| *Data of rainfall 01-09. 2023. Szarvas* | | | | | | | | | | | | | |
| **Months** | **Jan.** | **Febr.** | **Marc.** | **Apr.** | **Maj.** | **Jun.** | **July.** | **Aug.** | **Sept.** | - | - | - | **SUM** |
| Rainfall (mm) | 49,9 | 15,1 | 25,3 | 19,3 | 56 | 20,1 | 33,3 | 33,7 | 31 | - | - | - | 283,7 |

In our experiment, we compared two tillage methods with different irrigation water application rates. The two methods were conventional (ploughing) and minimum tillage. Irrigation was applied in combination. There were unirrigated, twice irrigated and four times irrigated plots. Thus, a total of 6 types of treatment can be distinguished. Each treatment was carried out in 3 replicates, so the total experimental area consisted of 18 plots. Each plot/replicate was 4x10 meters long, equating to an area of 40 $m^2$.

Based on the results of the soil analysis (collected before the experiment commenced in the autumn of 2021), the soil of the experimental area is slightly acidic, with a medium humus content and a clay loam physical texture. The soil did not contain CaCO3. The N-supply capacity was medium, the P-supply and the K-supply were high. *(Table 2)*

*Table 2*

Characteristics of the soil of the experiment (Szarvas, 2021. 0-30 cm soil layer)

| **Parameters** | **Value** |
|---|---|
| pH (KCl) | 6,75 |
| $K_A$ (Soil resistance) | 47 |
| $CaCO_3$ [%] | 0 |
| Hummus [%] | 2,43 |
| AL-$P_2$O5 [mg/kg$^{-1}$] | 2348 |
| AL-K2O [mg/kg$^{-1}$] | 665 |

*Conventional cultivation:* ploughing was done with reversible mould board plough in November 2021 and 2022. (depth of 30 cm)

*Minimum tillage:* No ploughing for the conservation tillage. Instead, a disc harrow was used to till the soil in late March 2022 and 2023. (depth of 5-10 cm)

The sowing of maize was completed on 10 May 2022 and 4 May 2023. The sowing was carried out with the usual 76,2 row spacing and at a rate of 70000 plants/ha per seed. The seed used was an early-maturing maize hybrid (FAO 350).

Irrigation is necessary to achieve good yields and optimal plant growth in maize production. In both years the irrigation (15 mm) was carried out in the days following sowing to ensure uniform growth, on 12.05.2022 and 08.05.2023. Afterwards, the crop was irrigated depending on the experiment.

1. first irrigation - 30 mm of water was applied to both of the areas, except for the unirrigated plots (30.05.2022 and 25.05.2023).

2. second irrigation - 30 mm of water was applied only to the four times irrigated plots (15.06.2022 and 12.06.2023).

3. at the third time, all plots were irrigated again (except the unirrigated ones) with 30 mm water (30.06.2022 and 26.06.2023)

4. Finally, the fourth irrigation was again only the quadruple irrigated parcel with 30 mm of water (18.07.2022 and 10.07.2023).

In our experiment, we conducted measurements of LAI (leaf area index) and SPAD (chlorophyll content was measured by SPAD 502 Plus). Additionally, we evaluated the average yield and soil compaction (was measured by penetrometer). The statistical analysis was performed using SPSS 29 software.

## RESULTS AND DISCUSSIONS

Yield is an important measure that illustrates the impact of treatments. We worked with the average sample of replicates. The yield averages represented by the charts are corrected for 14% moisture content. There are clear differences in yield. Without irrigation in droughty 2022, both tillages ended with yields of 3-4 t/ha, while in 2023, when rainfall distribution and amount were more favourable, yield averages increased to 4-5 t/ha. In contrast, in the two suitable irrigations, minimum tillage was inferior to conventional tillage, and this was particularly significant in 2023. Compared to the average of 4.8 t/ha for min-till, the conventional (conv-till) tillage yielded 7.53 t/ha. In 2022, there was no significant difference between these two treatments, with yields of 5.5 (min-till) and 6.2 t/ha (conventional tillage). Finally, in the 4x irrigated stand, the highest yield in 2022 was 6.88 t/ha achieved with minimum tillage, followed by 6.6 t/ha with rotational tillage. This was reversed in 2023, with conventional tillage yielding 8.51 t/ha, followed by min-tillage at 7.78 t/ha *(Figure 1 and Figure 2).*

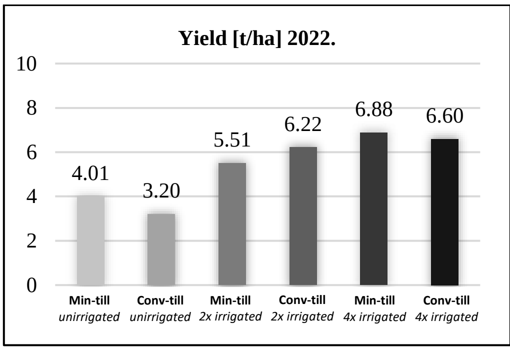


Fig. 1. (Yield of maize; Szarvas 2022)

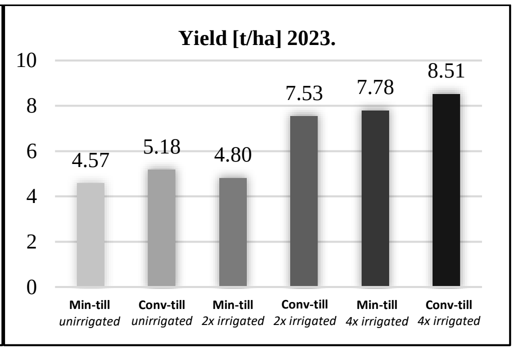


Fig. 2. (Yield of maize; Szarvas 2023)

Looking at the average yield of irrigation for the two tillages studied, the average yield for minimum tillage was 5.46 t/ha in 2022; and 5.72 t/ha in 2023. The yield for conventional tillage was 5.34 t/ha in 2022 and 7.07 t/ha in 2023. Thus, it is clear that in 2022 the minimum till achieved a higher average yield, while in 2023 the conventional till achieved a higher average yield *(Table 3).*

*Table 3*

Effect of tillage on maize yields averaged over irrigations [t/ha] (2022-2023)

| Tillage | Year | 0x irrigated | 2x irrigated | 4x irrigated | **Average** |
|---|---|---|---|---|---|
| Minimum-tillage | 2022 | 4,01 | 5,51 | 6,88 | **5,46** |
| | 2023 | 4,57 | 4,80 | 7,78 | **5,72** |
| Conventional-tillage | 2022 | 3,20 | 6,22 | 6,60 | **5,34** |
| | 2023 | 5,18 | 7,53 | 8,51 | **7,07** |

On the other hand, when looking at the average number of irrigations for the tillage, it can be seen that there is an increase in both years. Comparing the two study years, the highest yield was in 2023 compared to the previous year for irrigated crops, with the highest yield of 8.15 t/ha for the 4x irrigated stand and the average of the tillage *(Table 4)*.

*Table 4*

The effect of irrigation on maize yields averaged over tillage [t/ha] (2022-2023)

| Irrigation | Year | Min-till | Conv-till | **Average** |
|---|---|---|---|---|
| unirrigated | 2022 | 4,01 | 3,20 | **3,60** |
| | 2023 | 4,57 | 5,18 | **4,87** |
| 2x irrigated | 2022 | 5,51 | 6,22 | **5,86** |
| | 2023 | 4,80 | 7,53 | **6,17** |
| 4x irrigated | 2022 | 6,88 | 6,60 | **6,74** |
| | 2023 | 7,78 | 8,51 | **8,15** |

In summary, irrigation has a significant effect on yield averages, but tillage did not cause a significant difference. The weather of the year has a strong influence on which cultivation achieves a minimum higher yield. Comparing the two study years, it is clear that the more favourable growing season of 2023 had better weather and rainfall distribution, which improved yields.

The next measurement, which I took while the maize was still green (in August), was the leaf area index. In our experiment we could only measure it in 2022. In that year, the four times irrigated plot of min-till reached the highest LAI value of 2.8. This value means a relatively dense corn crop, so, it efficiently uses the available light for photosynthesis. This high LAI value usually indicates a good yield, as denser vegetation has a higher photosynthetic activity *(Figure 3)*.

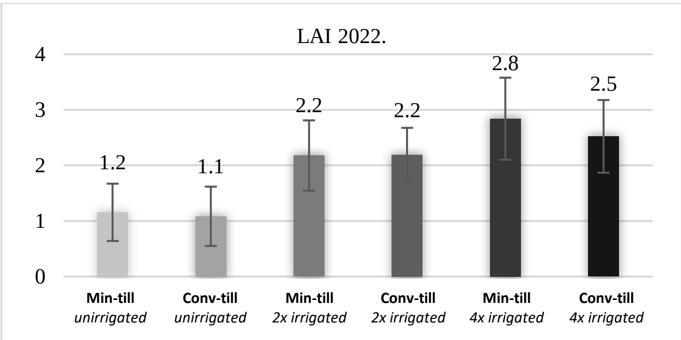


Fig. 3. (LAI of maize; Szarvas 2022)

The analysis of variance found that there is no significant difference between tillages but there is between irrigations. Compared to the unirrigated plots, 2x irrigation showed a significant difference, but 4x irrigation showed even more significant results *(Table 5)*.

LAI measurements proved that irrigation increases stand density, leaf area index and thus yield. Tillage did not significantly change LAI values.

*Table 5*

Leaf area index (LAI) under irrigation: analysis of variance 2022.

| Irrigation | Year | Average | Standard error | 95% confidence interval | |
|---|---|---|---|---|---|
| | | | | Lower limit | Upper limit |
| unirrigated | 2022 | 1,050* | 0,134 | 0,781 | 1,319 |
| 2x irrigated | | 2,255* | 0,134 | 1,986 | 2,524 |
| 4x irrigated | | 2,540* | 0,134 | 2,271 | 2,809 |

** significant difference (95% confidence level)*

The SPAD measurement was the other one in the green crop. The SPAD value refers to the chlorophyll content of the plant leaves, which provides indirect information on the condition and nutrient supply of the plants. In the experiment, the plants gave the highest average values after four waterings. The SPAD value was 58.22 for conventional cultivation and 58.83 for min-till. The lowest value was obtained in the min-till unirrigated plot *(Figure 4)*.

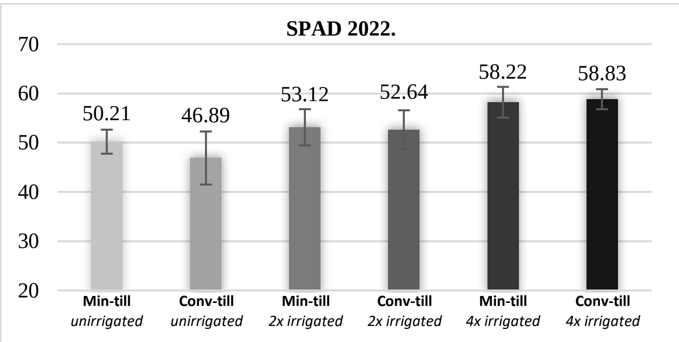


Fig. 4. (SPAD of maize; Szarvas 2022)

And by analysis of variance, a significant increase was observed between unirrigated and irrigated and between irrigated twice and irrigated four times. The 95% confidence upper limit for the unirrigated treatment was 50.184 SPAD chlorophyll content which was exceeded by the twice irrigated (52.880) and four times irrigated (58.525) experiments. No significant difference was detected in the analysis of tillage in this case. *(Table 6)* Thus, minimum tillage and conventional tillage had no significant effect on the chlorophyll content of maize.

*Table 6*

Chlorophyll content (SPAD) under irrigation: analysis of variance 2022.

| Irrigation | Year | Average | Standard error | 95% confidence interval | |
|---|---|---|---|---|---|
| | | | | Lower limit | Upper limit |
| unirrigated | 2022 | 48,550* | 0,816 | 46,916 | 50,184 |
| 2x irrigated | | 52,880* | 0,816 | 51,246 | 54,514 |
| 4x irrigated | | 58,525* | 0,816 | 56,891 | 60,159 |

** significant difference (95% confidence level)*

Finally, I compared soil resistance in the unirrigated and 4 times irrigated plots in both minimum-till and conventional cultivation. The measurements were carried out twice, on 31.08.2022 and 25.11.2022. The results of the unirrigated graphs demonstrate that the minimum-till reached the pressure of 600 N at an earlier depth of 13 cm, as observed at the end of August *(Figure 5)*. In comparison, the conventional tillage reached the same pressure at approximately 20 cm depth. In contrast, in the measurement at the end of November, the pressure increased more slowly for both cultivation techniques in the cultivated layer, so that the pressure was 277 N for minimum tillage and only 163 N for conventional tillage at 20 cm depth *(Figure 6)*.

The results showed that the pressure in the cultivated layer of a drier soil is higher than it was in a wetter soil. Furthermore, under unirrigated conditions the minimum tillage has a higher measured pressure at a specified depth compared to the conventional one, so that soil is more compressed.

Fig. 5. (Unirrigated soil resistance 2022.08.31)

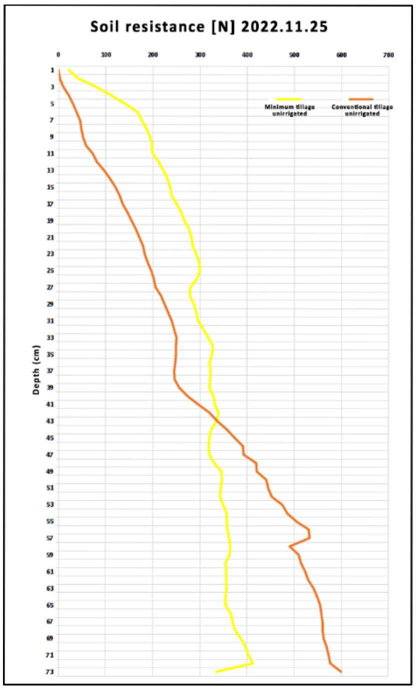

Fig. 6. (Unirrigated soil resistance 2022.11.25)

On the four times irrigated plots, a similar minimal difference can be observed compared to the previous one. On 31 August, the minimum tillage reached 500 N at 16 cm depth, while the ploughing only reached 500 N at 40 cm depth. In the cultivated layer (about 20 cm), the minimum tillage was still at 500 N at this time, while the conventional layer was close to 300 N *(Figure 7)*. At the end of November, the pressure was 222 N at a depth of 20 cm for min-till and 132 N for ploughing. Thus, overall, it can be concluded that soil resistance in all treatments (no irrigation, 4x irrigation) varies greatly with soil moisture *(Figure 8)*. The soil tested on both dates was found to be much more compacted on 31 August 2022 than on 25 November 2022. This may be due to the wet weather in November. In addition, irrigation in June and July has an effect on soil compaction even several months after application. Tillage also has an effect on soil resistance. In the cultivated layer, i.e. at about 20-25 cm, conventional tillage resulted in lower pressure than minimum tillage without deep ploughing. The difference is not significant, but it is noticeable in the graphs.

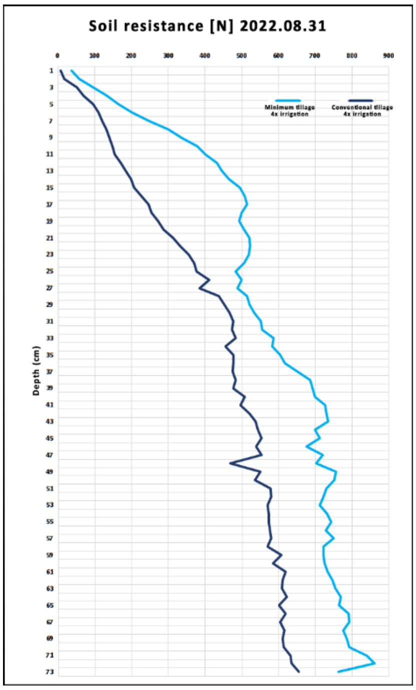


Fig. 7. (4x irrigated soil resistance 2022.08.31)

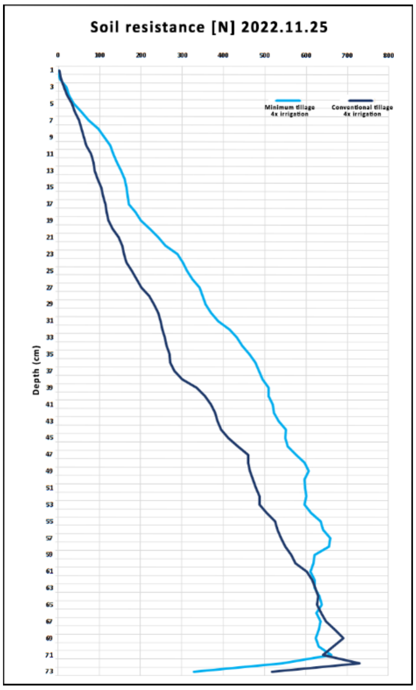


Fig. 8. (4x irrigated soil resistance 2022.11.25)

## CONCLUSIONS

Our study was conducted over a two-year period, from 2022 to 2023. The research involved the examination of different numbers of irrigations and two contrasting tillage systems.

The yield was one of our most important measurements. Irrigation had a significant effect on the averages, but tillage did not make a significant difference. The weather of the year was the factor that determined which cultivation achieved the higher yield. The 2023 growing season had more favourable weather and rainfall distribution, which helped to achieve higher yields. The leaf area index (LAI) has shown that irrigation increases the density of maize stands, and thus the leaf area. However, there was no significant difference between the tillages. Our next measurement was chlorophyll content (SPAD), which was also measured while the stand was still green. Analysis of variance showed that there was a significant increase in chlorophyll content in irrigated plots compared to non-irrigated plots. However, there were no significant differences between the tillages in these cases too.

Finally, soil resistivity showed that soil pressure varies greatly with soil moisture. On average, the soil was much more compacted on 31.08.2022 than on 25.11.2022. And at a depth of about 20-25 cm, conventional tillage resulted in lower pressure than minimum-tillage with no deep tillage.

So, to summarize my measurements, I can conclude that irrigation has a positive effect on corn in many respects. It is worthwhile to irrigate up to four times during the critical phenological phase, because it can increase yields much more. And without irrigation, maize is less recommended, as it is highly vulnerable to extreme weather conditions. From the comparison of the tillages, I concluded that there was no significant difference between minimum and conventional tillage over the two years in most cases. Literature suggests that minimum tillage has a positive effect after at least two years, which I have not yet reached in my studies. It is therefore advisable to continue the experiment. However, min-till is economically much more economical than conventional rotational tillage and my results show that in many cases there is no significant difference between them. Therefore, the use of minimum-tillage in maize cultivation is recommended.

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