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# EFFECT OF SOIL CONDITIONING ON SOIL PENETRATION RESISTANCE AND TRACTION POWER DEMAND OF PLOUGHING

GÉZA TUBA[1], GYÖRGYI KOVÁCS[1], LÚCIA SINKA[1,2], PÁL NAGY[2], ARZU RIVERA-GARCIA[1,2], ZUZANA BAJUSOVÁ[3], PAVOL FINDURA[3], JÓZSEF ZSEMBELI[1*]

[1]Research Institute of Karcag, Hungarian University of Agriculture and Life Sciences, Karcag, Hungary
[2]Kerpely Kálmán Doctoral School, University of Debrecen, Debrecen, Hungary
[3]Slovak University of Agriculture in Nitra, Nitra, Slovak Republic

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Soil compaction and degradation due to improper tillage are problems involving significant natural and economic damages. On compacted soils, suitable cultivation can be implemented only with higher energy and traction force input. In our study, the effect of a soil conditioner (Neosol) was examined on the penetration resistance of the soil and the traction power demand for ploughing in the experiment set up in the East-Slovak Plain in 2017 – 2018 to justify several preliminary results showing that long-term soil conditioning results in enhanced root system, improved soil structure, cultivability, water- and salt regime. We found a positive effect of Neosol application with both investigated parameters and its long-term effect was also justified. The penetration resistance values of the soil of the untreated plot were 17 – 23% higher, while the traction power demand values were 9 – 32% lower in comparison with the Neosol treated plot in the first and the second year of the study, respectively. We assume the cumulative positive effect of soil conditioning on the physical soil properties in the study area, therefore the long-term application of Neosol is recommended for farms having similar soil properties.

Key words: soil compaction, penetration resistance, traction power, soil conditioning

Ploughing was the only basic operation of soil cultivation for a long time, even recently it is the most common procedure in soil preparation. Nevertheless, ploughing is one of the most energy demanding tillage operations in crop production. Depending on the soil status, tillage without turning the upper soil layers has 10 – 50% lower energy demand compared to ploughing (Moitzi *et al.* 2013). There is a positive correlation among the energy demand, the fuel consumption and the intensity of soil cultivation, all these depend on the number and the depth of the tillage operations, and the type of the tools applied (Godwin 2007). Due to the large surface and the soil structure turning action of the mouldboard, ploughing is the most intensive tillage operation and induces high soil resistance. Soil resistance to ploughing is that force which is generated by the soil against the tillage tool involving the resistance of the soil particles against dissevering, the surface friction between the soil and the tillage tool, the soil mass, and the friction between the soil particles (Birkás 2008). Compacted soils have high mechanical resistance, according to the literature, soil is considered harmfully compacted if its penetration resistance is higher than 3 MPa or its bulk density exceeds 1.5 g/cm$^3$ (Soane & Ourwerkerk 1995). Due to compaction,

József Zsembeli (*Corresponding author), Research Institute of Karcag, Hungarian University of Agriculture and Life Sciences, Karcag, Hungary. E-mail: zsembeli.jozsef@uni-mate.hu

the mechanical resistance and the bulk density of soils are increasing, while their porosity is decreasing, all these result in lower biological activity, infiltration rate, hydrological conductivity, and aeration. As a consequence of these unfavourable processes, the water and nutrient uptake of crops is limited as well as root development, furthermore the risk of water loggings and the appearance of excess waters is increasing (Nyiri 1993; Birkás 1996). Several researchers found soil resistance to be a more sensitive parameter than soil bulk density to express the degree of soil compaction (Freitag 1971; Pigeon *et al.* 1977; Sanchez 1990). The penetration resistance of the soil measured by means of a penetrometer means the force needed for inserting the probe of the penetrometer into the soil. Penetrometers are very suitable tools for checking the quality of tillage and for quantifying the effects of soil amendments and conditioners (Sinóros-Szabó & Szőllősi 1999; Tuba 2013; Tuba *et al.* 2020). The energy demand of soil cultivation is generally characterised by fuel consumption, though it is also possible to determine the soil resistance against the actually used cultivation tool, which means the traction power or pull force required to move the tractor (Al-Jalil *et al.* 2001; Forgács & Czimbalmos 2008; Md-Tahir *et al.* 2021). The moisture content of the cultivated soil layers must be considered as it is in negative correlation with the penetration resistance of heavy textured soils (Campbell & O'Sullivan 1991).

Soil conditioning means the application of yield increasing and bio-stimulant materials that positively influencing the physical, chemical, and biological properties of the soil. Recently, the application of bio-stimulants is extensive as they ensure better utilisation of the yield potential of crops, consequently resulting in increased yields, higher quality, and stronger pest tolerance or even resistance (Kováč *et al.* 2017; Kocira *et al.* 2020a; 2020b; 2020c). In our study, Neosol (formerly called PRP-SOL) was applied, which is a concentrated, premium quality soil conditioner. Due to its substances originating from sea algae and the MIP (Mineral Inducer Process) technology, Neosol supplies the trace elements essential for the enzymatic activities of the soil microflora involved in mineral assimilation by the plants. It enhances the biological activity of the soil, consequently increases soil fertility (I1). The main goal of the application of Neosol is to improve the soil properties through aiding the extraction and transformation of nutrients to forms available by the plants (Sulewska *et al.* 2016). Soil conditioning applied in some consecutive years results in looser and improved soil structure and better cultivability due to the enhanced biological activity and the extended root system (Szűcs *et al.* 2015; Urbanovicova *et al.* 2018). In their preliminary study, Zsembeli *et al.* (2019) established that the application of Neosol had a positive impact on the water and salt balance of the soil by the improved infiltration and percolation, and also contributes to preserving more water in the root zone.

This study was aimed to determine and quantify the effects of Neosol on the penetration resistance of the soil and on the traction power demand of ploughing in the second and third years after the first application in a field experiment.

## MATERIAL AND METHODS

The experiment was carried out close to the village of Stretavka, Slovakia in 2017 and 2018. The study area is located near the Eastern-Slovakian Plain, on the flood plain of Uh, Latorica, and Čierna Voda rivers at the altitude of 102 m. The average groundwater level fluctuates between 1 and 1.5 m. The coordinates of the experimental plots are 48°36'47.4"N 21°58'38.3"E. The soils of the area were formed on eolic Quaternary loess and river sediments containing 50 – 70% quartz, 15 – 20% clay minerals and calcium-carbonate with sandy loam texture.

The experiment was set up in 2016, when the application of Neosol was started to establish its effect on the soil and the yields of the crops grown there. Our measurements were accomplished on two plots of the experiment, where conventional tillage based on ploughing to the depth of 0.25 – 0.28 m is applied. The soil moisture, penetration resistance and traction power measurements were conducted on 9$^{th}$ October 2017, while on 8$^{th}$ November 2018, when the soil status was optimal for ploughing. The size of the Neosol treated plot is 10 ha, while the control plot is 11.9 ha (Figure 1).

Soybean was grown in the investigated plots in 2016, winter wheat in 2017, and spring barley in 2018, respectively. Neosol was applied parallel (in the same operation) with fertilisation in the dose of 200 kg/ha before sowing each year, then it was mixed into the upper soil layer (0 – 0.1 m) when the seedbed was created. The main parameters of Neosol soil conditioner are summarized in Table 1.

*Measurement of soil moisture content*

The soil moisture content (v/v%) was measured in the layers of 0 – 0.1 m, 0.1 – 0.2 m, and 0.2 – 0.3 m in 3 repetitions by means of an "SMT 100" probe (Umwelt-Geräte-Technik GmbH, Munich, Germany). The averages of the 4 repetitive measurements were calculated and illustrated. The "SMT 100" probe device is compact, robust but also elastic and durable, therefore versatilely applicable for the


Figure 1. Satellite photo of the experimental plots taken in 2016.
Note: 1 – Control; 2 – Neosol treated, the red lines show the tracks of the traction power measurements.

in-situ measurements of the soil moisture content. This device combines the advantages of a low-cost frequency domain reflectometry (FDR) system with the accuracy of a time domain reflectometry (TDR) system (I2), therefore we gained reliable data even in the heavy textured soil of the investigated plots.

*Measurement of penetration resistance*

The penetration resistance of the soil was measured by means of a „3T System" (3T System Bt., Hungary) electronic layer indicator (penetrometer) developed by Sinóros-Szabó and Szőllősi (1999) in five replications in each treatment in the soil layer of the basic cultivation (0−30 cm). The penetrometer detects the force needed to insert the probe ending in a 60° cone into the soil and records the resistance values expressed in MPa calculated from the surface area of the cone and the detected force for each 0.01 metre thick soil layer during the measurement. The data gained from the upper 0.05 m soil layer were not evaluated as they are not reliable due to the so called 'soil surface effect'.

*Determination of traction power demand of ploughing*

A special device system was used to determine the traction power demand of ploughing. The system consists of two load cells (force transducers) and a measuring frame connected to a Hottinger Baldwin Messtechnik (Darmstadt, Germany) Spider-8 mobile digital data logger (Figure 2). The load cells detect the force between the tractor and the plough

T a b l e 1

Main parameters of Neosol

| CaO | MgO | pH | Bulk density | $Na_2O$ | $K_2O$ | N | $P_2O_5$ | Particle size |
|---|---|---|---|---|---|---|---|---|
| 27% | 16% | 7.2 | 1.2 g/cm$^3$ | 4.5% | 0.7% | 0.3% | 0.03% | <0.32 mm |

Source: Olmix Group (I1)

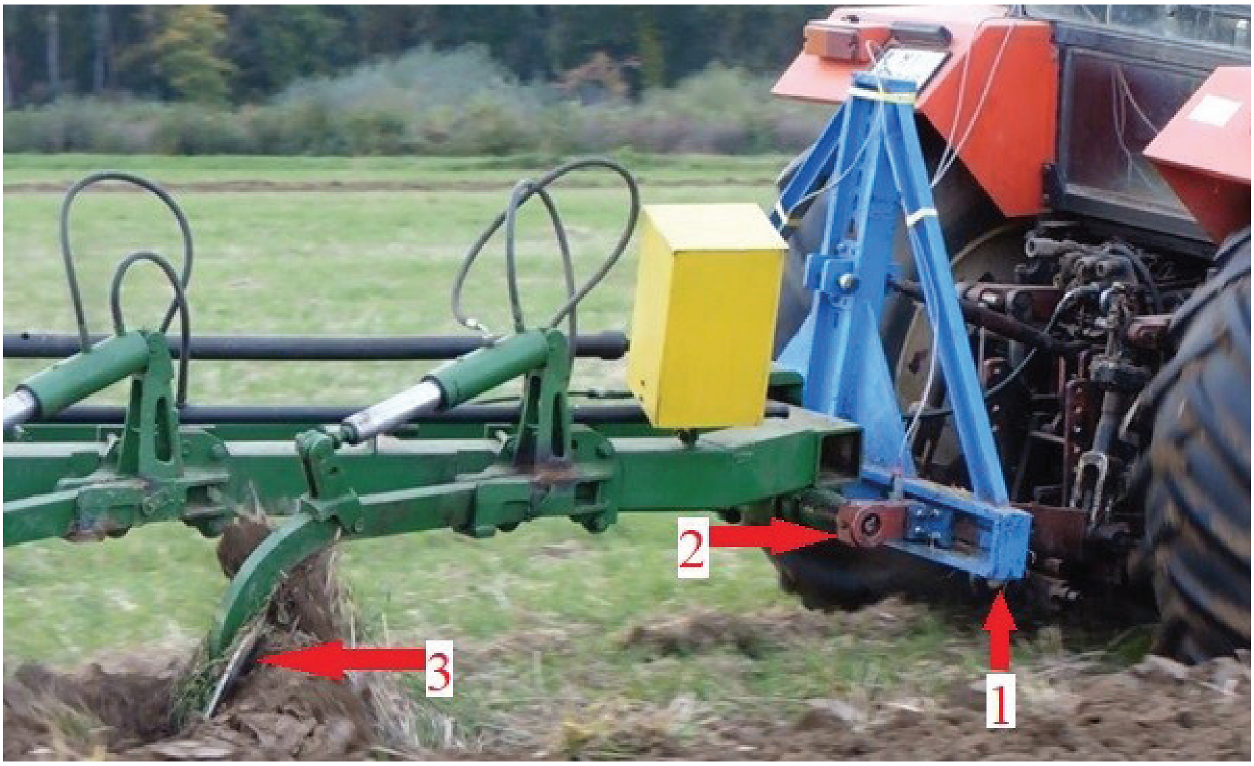


Figure 2. Measurement of traction power demand of ploughing in Stretavka, 2018. 1 – measurement frame; 2 – load cell; 3 – mouldboard of the plough.

and converts it into an electrical signal that can be detected by the data logger. The signals are transformed, recorded and displayed as real-time dynamic data by the „Catman 4.5 Release 3" software in a connected computer. The frequency of records during our measurements was 0.2 seconds. These measurements were done in two replications on both plots. The data gained for the more compacted ends of the plots, where the tractors turn back, were not considered during the data processing. The re-


Figure 3. Soil profiles before and in the investigated years.

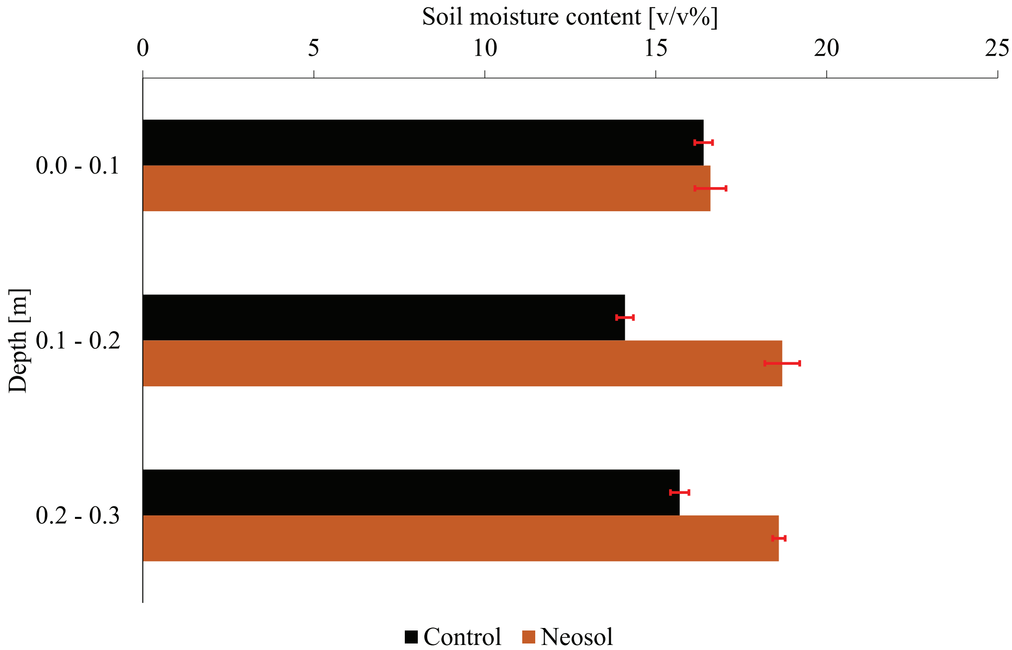


Figure 4. Soil moisture contents in 2017 (averages of 4 repeated measurements with the standard deviations).

cording of the data was started when the tractor pulling the plough reached the speed of 6−7 km/h and stopped when slowed down at the end of the plot. Using this way, we gained and analysed two times 800 data for both plots, the averages of the two data series were illustrated.

The penetration resistance data were processed by means of the own software of the "3T System", while the "Catman 4.5 Release 3" software was used to process the traction force data. Further analyses and illustrations were done by using Microsoft Excel 2016 software. We used descriptive statistical analyses and one-way analysis of variance for the further evaluation of the soil moisture content, soil

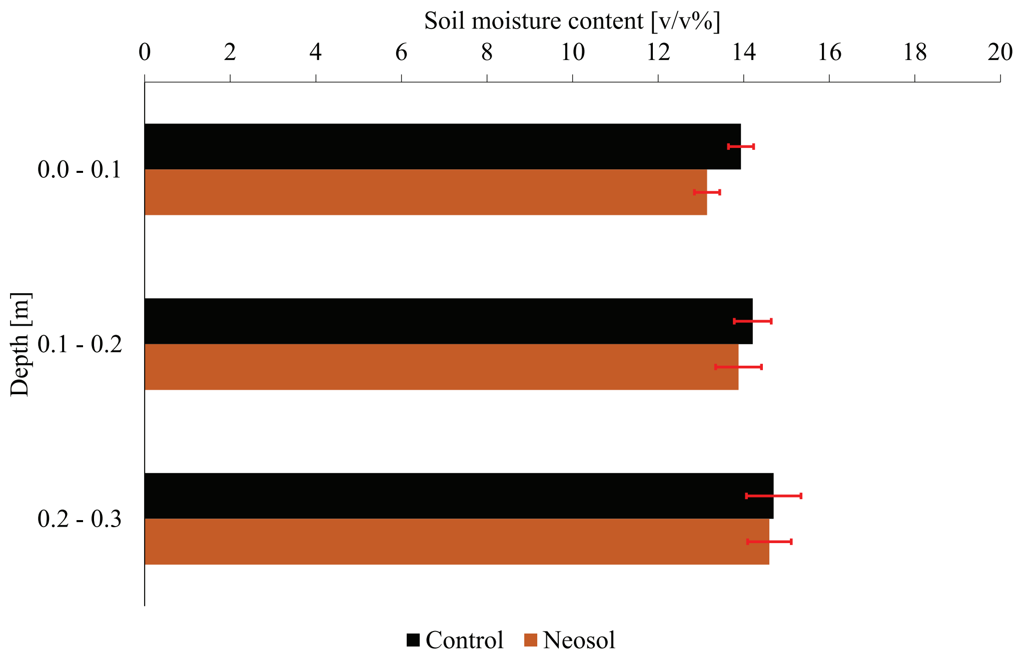


Figure 5. Soil moisture contents in 2018 (averages of 4 repeated measurements with the standard deviations).

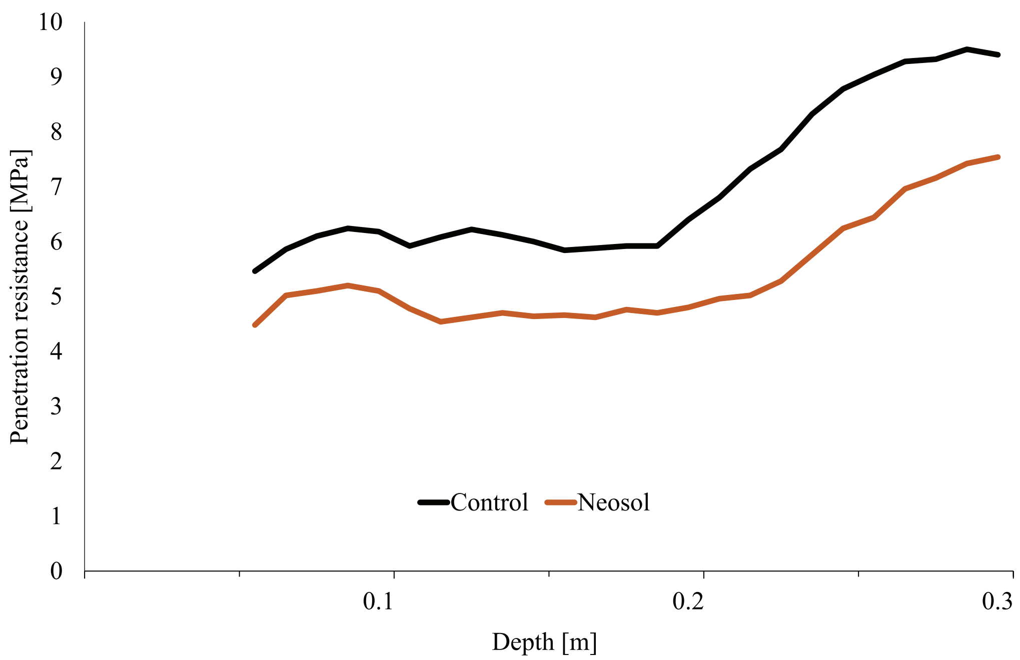


Figure 6. Effect of soil conditioning on the soil penetration resistance in 2017.

penetration resistance and traction power data, respectively.

## RESULTS

*Development of the soil structure*

Pits were dug in the plots of the experiment each year (5th July 2016; 17th May 2017; 1st June 2018) to study the soil profiles (Figure 3), but no extensive data were quantified for describing the agronomic structure of the investigated soil. Nevertheless, although 2018 was a year with unfavourably dry vegetation period, which is indicated by the colour and the compactness of the soil, the development of the thickness of the soil layer with favourable agronomic structure and the deepening root zone were visible and impressive.

*Soil moisture status*

At the date of the measurements in the autumn of 2017, the moisture status of the soil was favourable in terms of soil cultivation. Comparing the Neosol treated and the untreated control plots (Figure 4), it can be confirmed that the soil moisture content of the upper 0.1 m layer was very similar, but in the lower layers, more moisture was preserved in the soil of the plot treated with the soil conditioner.

In the autumn of 2018, the soil of the experimental plots was drier than the optimum at the date of the measurements. In the three investigated layers, the soil of the untreated plot was wetter, but the differences were not considerable (Figure 5).

*Effect of soil conditioning on the soil penetration resistance*

Based on the penetration resistance results, we found statistically different values for the treated and the control plots (Control: 7.02 MPa, Neosol: 5.38 MPa, *LSD* 5% = 0.23 MPa) in 2017. The soil of the Neosol treated plot was more favourable in the whole studied profile (0−0.3 m) at the date of the measurements (Figure 6). The differences are larger than it could be caused by the differences in the actual soil moisture contents, therefore, we assume a soil structure improving effect of soil conditioning in that case.

At the date of the measurements in 2018, the soil of both investigated plots was compacted (Figure 7) based on the penetration resistance data, though the treated soil was less compacted in the whole profile and showed increasing tendency with the depth. The soil of the untreated control plot was unfavourably compacted even in the upper (0.06−0.2 m) layer with an average value of 8.2 MPa). The lower 0.2−0.3 m layer was extremely compacted, we

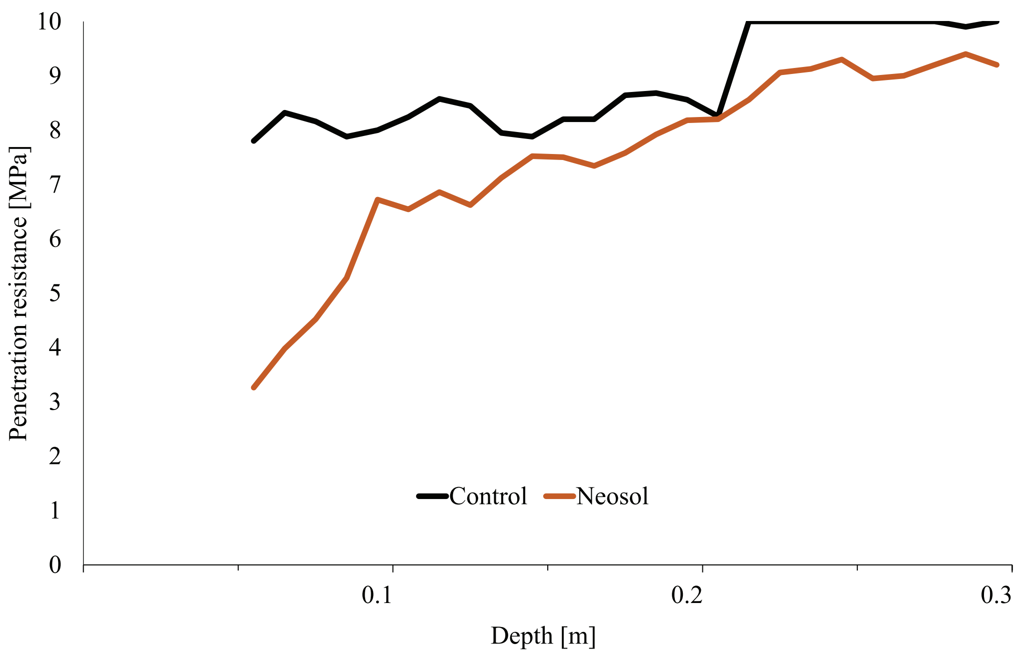


Figure 7. Effect of soil conditioning on the soil penetration resistance in 2018.

detected 10 MPa, which is the upper threshold of the measurement range of the device we used, therefore it can be possible that even higher values were characteristic to that layer that we were not able to record.

Similarly to the previous year, we found a significant difference between the penetration resistance of the soils of the Neosol treated and the untreated control plots in 2018 (Control: 8.64 MPa, Neosol: 7.18 MPa, *LSD* 5% = 0.29 MPa).

Comparing the penetration resistance in the cultivated soil layer (0 − 0.3 m) in the two investigated years, we found increasing values for both treatments, which is probably in close correlation with the soil moisture content differences. In both years, the most frequent values (Mode) measured in the

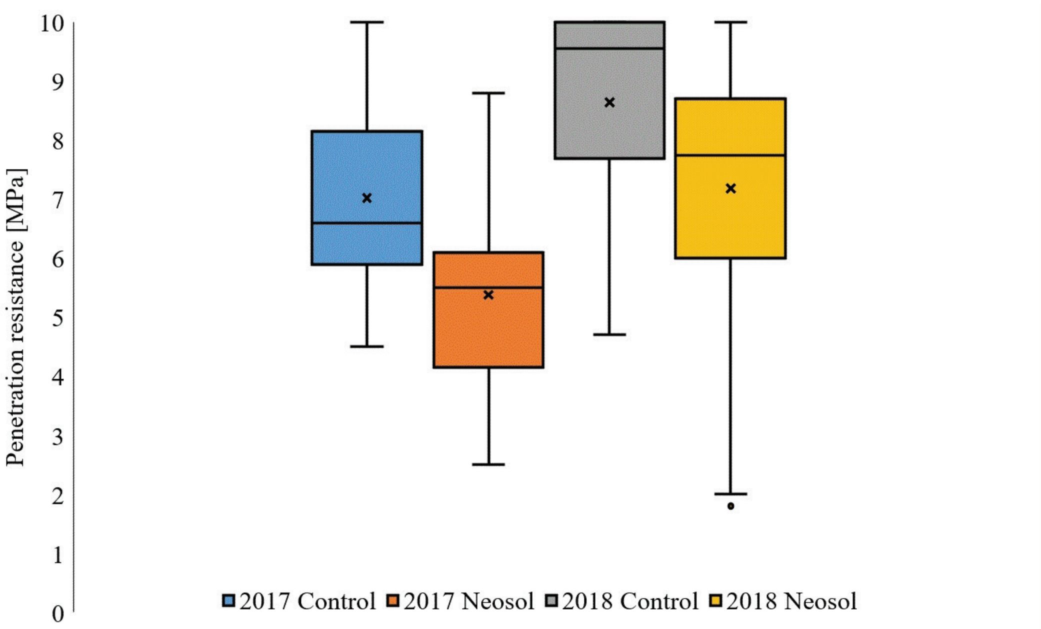


Figure 8. The soil penetration resistance data for 2017 and 2018.

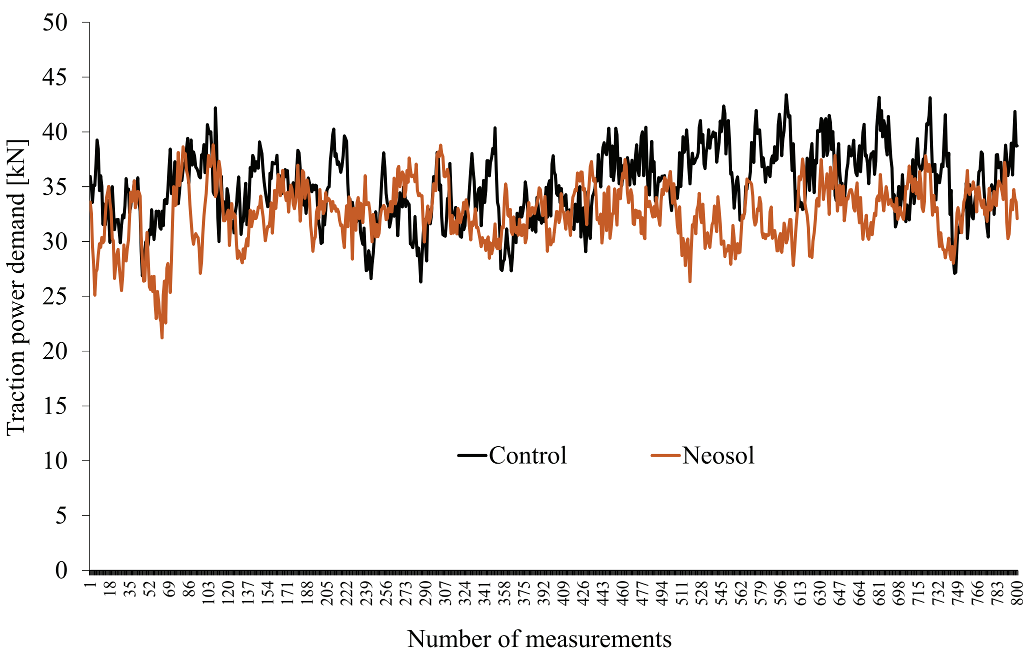


Figure 9. Effect of Neosol treatment on the average traction power demand of ploughing in 2017.

control plot were 10 MPa, which is the upper threshold of the measurement range of the penetrometer. In the case of the Neosol treatment, the majority of the penetration resistance values were under the Median (Figure 8).

*Effect of soil conditioning on the traction power demand*

In 2017, the differences in the traction power demand of ploughing were similar to the differences in the soil penetration between the Neosol treated and the untreated plots. 1600 data were considered and assessed for both plots (Figure 9). Due to the high measurement frequency, the data show a certain deviation for both plots, nevertheless the standard deviation for the data measured in the soil of the Neosol treated plot was nearly 1 kN lower than of the nontreated control (Table 2). That means a more even traction power demand of ploughing on the treated plot, while wider data range, higher maximum and lower minimum values with slightly larger standard error are characteristic to the untreated control. The average traction power demand of ploughing is lower for the Neosol treated plot and significantly differs from the control at the confidence level of 95% (*LSD* 5% = 0.18 kN).

In 2018, under compacted soil conditions, significantly less traction power demand was characteristic to pull the plough with five mouldboards in the case of the plot treated with Neosol in comparison with the untreated control plot (Figure 10). Just like in 2017, 1600 data were processed for each plot (Table 3). Higher traction power was needed to cultivate the control plot, the minimum and maximum values were higher with the standard deviation and error values nearly the same in comparison to the treated plot. The averages values significantly differed (*LSD* 5% = 0.16 kN).

## DISCUSSION

Analysing the soil moisture content data, we could figure out only a little difference in the 0.1 − 0.3 m layer between the variants when the soil moisture contents were in the range of 14 − 19 v/v% in 2017, but we do not consider this difference as the effect of Neosol application. In 2018, all the soil moisture data were approximately 14 v/v%, the differences were within 1 v/v%, which cannot be considered a treatment effect.

We found the soil of the untreated control plot being more compacted in both years, its penetration resistance values were 23.4% higher in 2017, while 17% higher in 2018 in comparison with the Neosol treated plot, respectively. Comparing the two investigated years, it could be concluded that the higher soil moisture contents due to the more favourable weather conditions, lower penetration resistance values were detected in 2017, contrary to the extremely high values recorded for the dry season of 2018.

The traction power demand of ploughing showed higher values in the case of the untreated control plot in both study years. The force needed to pull

Table 2

Descriptive statistics of the traction power demand (kN) data for 2017

| | Control | Neosol |
|---|---|---|
| Mean | 35.12 | 32.52 |
| Standard error | 0.12 | 0.10 |
| Deviation | 4.76 | 3.89 |
| Variance | 22.66 | 15.12 |
| Minimum | 16.91 | 17.46 |
| Maximum | 48.03 | 43.07 |
| Number of cases | 1,600 | 1,600 |
| Confidence (95.0%) | 0.233 | 0.191 |

Table 3

Descriptive statistics of the traction power demand (kN) data for 2018

| | Control | Neosol |
|---|---|---|
| Mean | 33.66 | 22.78 |
| Standard error | 0.10 | 0.10 |
| Deviation | 3.85 | 4.03 |
| Variance | 14.82 | 16.21 |
| Minimum | 24.80 | 15.21 |
| Maximum | 47.45 | 40.79 |
| Number of cases | 1,600 | 1,600 |
| Confidence (95.0%) | 0.19 | 0.20 |

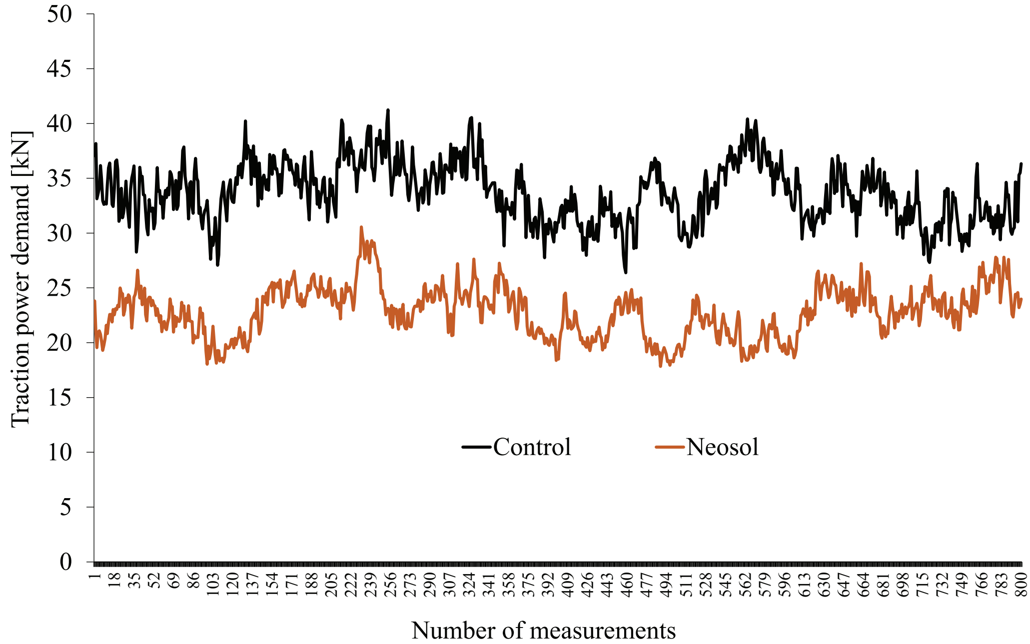

Figure 10. Effect of the Neosol on the average traction power demand in 2018

the plough by the tractor was not truly manifested in the difference we figured out in the soil moisture contents between the two plots. The average traction power demand of ploughing was nearly the same on the control plot in both years, while the Neosol treatment resulted in a considerable (30%) decrease from one year to the other. Nevertheless, we suspect a long-term, cumulative effect behind that decrease (improvement), which was also justified in other studies. Several researchers reported about the significant correlation between the penetration resistance of the soil and the yields; soil resistance above the optimal threshold results in yield depression and lower quality. A high degree of compactness in the deeper soil layers impedes water and nutrient movement, while the compacted topsoil has a negative effect on root development and aeration in the soil (Neményi *et al.* 2006; Trusic *et al.* 2008; Whalley *et al.* 2008). This improving effect was also proven by Bajus (2020), who found a 12.7% higher yield of winter wheat in 2017 and 4.9% extra yield of summer barley in 2018 due to soil conditioning with Neosol in comparison with the untreated controls, respectively. We assume that higher yield is in correspondence with higher root mass that results in a more intensive soil loosening effect and a more favourable soil structure.

## CONCLUSIONS

Based on our experimental results, it can be concluded that the penetration resistance and traction power values characterising and quantifying the compactness and cultivability of the soil were lower hence more favourable on the plot treated with Neosol soil conditioner in both investigated years. From the point of view of farmers, the main goal of the application of soil conditioners is to ensure better growing conditions for the crops, hence to achieving higher yield quantity and quality. Nevertheless, our study pointed out that Neosol application resulted in a much lower traction power demand of ploughing by the second year of the study even under unfavourable (dry soil status) conditions. Based on this observation, we assume a cumulative positive effect of soil conditioning on the physical soil properties in the study area, therefore the long-term application of soil conditioners with identical features is recommended for farms having similar soil properties.

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