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Identification of the resistive force of the tool on the basis of georadar measurements

***Abstract**. In Europe, the area of soil degraded by over-compaction is estimated at 33 million hectares. The aim of the research was the potential working resistance of the tool in the soil medium based on the analysis of the GPR echogram. The scope of the research included strain gauge measurement of the tool working resistance force in the TUZ. The experiment included several ranges of tool operating depth, the limit of which was tractor drive wheel slippage exceeding 50%. The measurement of compactness was carried out in the trace of the tractor drive wheels at intervals resulting from subsoil variability; the depth of soil penetration was 0.8m. GPR scanning using the reflexive profiling method was carried out in the tractor wheel track, which was at the same time the footprint of the measurement of the working resistance force. Comparison of the obtained characteristics, i.e. working resistance force and echogram gave satisfactory results, however, it should be noted that their use is limited to a homogenous soil environment. In case of changes in the soil environment, the measuring system should be calibrated each time, so that the GPR echogram is adequate to the generated resistance force of the tool or soil compactness determined with the penetrometer. It was observed that: a) the number of passes less than four influenced only the compaction of topsoil up to the level of 0.2m, whereas with a greater number of passes this influence was also transferred to lower layers of the soil profile, b) each of the methods showed on average over 2 times increase in compactness between the profile of non-compacted soil and that of soil after eight passes by the tractor wheels.*

***Streszczenie.** W Europie powierzchnię gleb zdegradowanych w wyniku nadmiernego zagęszczenia szacuje się na 33 mln ha. Celem badań był potencjalny opór roboczy narzędzia w ośrodku glebowym na podstawie analizy echogramu GPR. Zakres badań obejmował tensometryczny pomiar siły oporu roboczego narzędzia w TUZ. Eksperyment obejmował kilka zakresów głębokości pracy narzędzia, których granicą był poślizg kół napędowych ciągnika przekraczający 50%. Pomiar zwięzłości przeprowadzono w śladzie kół napędowych ciągnika w odstępach wynikających ze zmienności podłoża; głębokość penetracji gruntu wynosiła 0,8 m. Skanowanie georadarowe metodą profilowania refleksyjnego przeprowadzono w śladzie kół ciągnika, który był jednocześnie śladem pomiaru siły oporu roboczego. Porównanie uzyskanych charakterystyk, tj. siły oporu roboczego i echogramu dało zadowalające wyniki, jednak należy zaznaczyć, że ich zastosowanie jest ograniczone do jednorodnego środowiska gruntowego. W przypadku zmian środowiska gruntowego należy każdorazowo kalibrować układ pomiarowy, tak aby echogram GPR był adekwatny do generowanej siły oporu narzędzia lub zwięzłości gruntu wyznaczonej penetrometrem. Stwierdzono, że: a) liczba przejazdów mniejsza niż cztery wpływała jedynie na zagęszczenie wierzchniej warstwy gleby do poziomu 0,2 m, natomiast przy większej liczbie przejazdów wpływ ten przenosił się również na niższe warstwy profilu glebowego, b) każda z metod wykazała średnio ponad 2-krotny wzrost zagęszczenia pomiędzy profilem gleby niezagęszczonej a profilem gleby po ośmiu przejazdach kół ciągnika. (**Identyfikacja siły oporu narzędzia na podstawie pomiarów georadarowych**)*

Keywords: georadar, force of the tool,
Słowa kluczowe: georadar, siła oporu narzędzia

Introduction

Spatial identification of soil compaction anomalies in the soil profile under production conditions is a key issue of modern production systems, which has wide practical applications [1]. Currently, the isolation of areas of concern on the field surface is very complex and burdened with low accuracy or high cost. In Europe, the acreage of soil degraded due to its excessive compaction is estimated at 33 million hectares. The experiments carried out on an area of 900 hectares, only with a penetrometer, allowed eliminating half of the area that was to be subsoiled. Assuming that 30 liters of fuel are needed for 1 ha, on the above-mentioned area the saving is 13500 liters and about 500 hours of human machine work. Yield increase may reach up to 30% on compacted soils and up to 15% on soils in good cultivation. The cost of subsoiling 1 ha is 450 zł/ha (CGFP), so the saving in case of the above mentioned area service is 202500 zł. The solution can be the geo-radar method which is one of the most advanced methods from the group of geophysical measurements. This method has been applied in many fields, among others in agriculture. During the measurement, a series of parallel profiling is performed, which allows interpolating the results between successive profiles, and the result itself is presented in the form of clear maps at any depth level [2,3,4]. The essence of the problem is to estimate the level of convergence between the geordar signal and soil compactness, which translates into resistance to tillage tools. Precise determination of this relationship would allow the use of the GPR method to control tillage tools. However, one should be aware that the soil medium is a rapidly changing environment in terms of moisture content and structure, which makes it difficult to match the amplitude of the GPR signal with the strength of the tool's working resistance. Among the many authors involved in mapping the variation of soil mechanical resistance in the form of horizontal drag force using a model tool, we can mention [5,6,7,8]. The first two, of the aforementioned papers, describe the design and field testing of a sensor in the form of a single chisel dragged in the soil at a depth of 0.3 m at a constant speed of 5 km/h. Budyn et al. [9] used the system used in precision agriculture LH-5000 to measure the slippage of one of the drive wheels of the tractor.

Material and methods

The aim of the research was to determine the relation between GPR signal amplitude and resistance force of subsoiler, which is a reference tool and soil compaction degree marker. The soil was compacted by tractor wheels, and variation of the degree of compaction resulted from the number of times the tractor wheel travelled along the same track. The working resistance of the subsoiler was measured with a strain gauge frame equipped with six strain gauge sensors working in the full bridge system [4,5,10]. The system of sensors allows measuring the forces occurring in each of the linkages of the three-point linkage of the tool and allows determining the load on the rear axle of the tractor, which is the driving axle. The actual speed was measured with the CORREVIT L-400 optical sensor placed in the tractor driving wheel axis of symmetry. The theoretical speed was measured with magnetic sensors attached to the rims of the tractor drive wheels. An H-CE optical sensor was used to measure the soil penetration depth. All measuring systems were connected to a CF-29 class portable computer via Daq Book/200A measuring station. The system used allowed operating in the frequency range of 1 Hz to 10 Hz. In each variant of compaction, GPR scanning using the reflection profiling method (Figure 1a) and strain gauge measurement of forces in the three-point suspension system of the tool on the tractor (Figure 1b) were carried out.

a) b)

Fig. 1. View of the GPR measurements (a) and strain gauge frame with calibration tool

The electromagnetic wave velocity (v) and dielectric constant (k) are strongly dependent on the soil water content (θ), due to the high dielectric constant of water compared to other materials (K for water = 80, K for different geological materials =5-15 and K for air =1), e.g. the relative electrical permeability of wet sand is eight times higher than the relative electrical permeability of dry sand [11-14]. Consequently, soil moisture measurements were made at intervals of 10 cm deep into the studied profile The study was carried out using an 800 MHz (Figure 2) shielded antenna allowing for a wavelength of 0.12 m and a resolution of 0.03 m [2].

Fig. 2 . GPR antenna used in the study

It was assumed that the run-up sections for GPR measurements would constitute 10% of the measurement section length and the effective length of this section was 10m.

Results

Figure 3 shows the amplitude characteristics of the GPR signal, identifying the variation in soil texture in the layer from its surface to a depth of 0.35m. The characteristics are superimposed and the number next to the color of the surface under a given characteristic indicates the degree of soil compaction on a scale from 1 (least compaction) to 5 (most compaction).

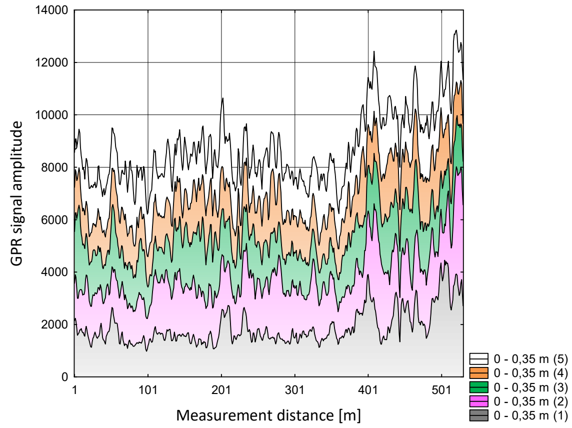

Fig. 3. GPR signal amplitude for different variants of soil compaction

The analysis of the GPR signal amplitude characteristics showed that the highest variation occurred in the case of non-compacted soil, and the lowest in the case of fully compacted soil. It should be noted that in the final part of the measurement section, a sharp increase in signal amplitude occurred irrespective of the degree of soil compaction. The analysis of GPR signal amplitude variation showed that the highest values were characteristic for the first two combinations, i.e. non-compacted soil and soil compacted by a single tractor pass (Figure 4). The lowest variability of signal amplitude was characteristic for the most compacted soil, where the range of variability was several times smaller than in the case of non-compacted soil.

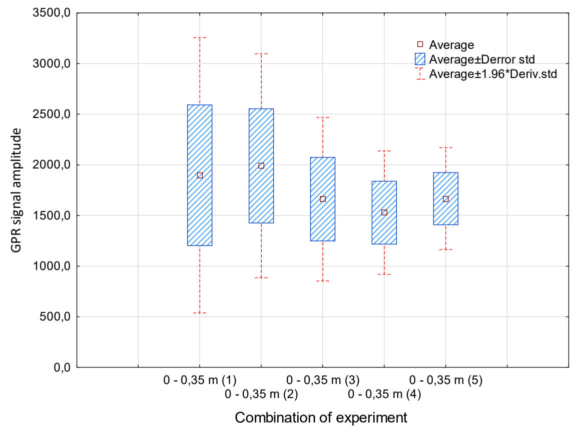

Fig. 4. Range of variation in GPR signal amplitude for different soil compaction variants

Figure 5 shows the resistance force characteristics of the gauge tool that was run in the soil compaction tracks for each combination of the experiment. The soil penetration depth of the reference tool was 0.35m. It was observed that the highest values of forces were recorded for the last combination of the experiment where soil compaction was the highest. The lowest force values were recorded for the zero test, i.e. non-compacted soil (Measurement 1). It was found that the characteristics of the force course along the measuring section were similar for all measuring runs except for test No. 5.

The level of variation of the working resistance force was at a similar level regardless of the experiment combination, while the value of this force increased with increasing soil compaction level (Figure 6). In the case of the highest soil compaction, the value of the resistance force was over 11 kN, while in the case of the zero test, the value of the force was twice lower.

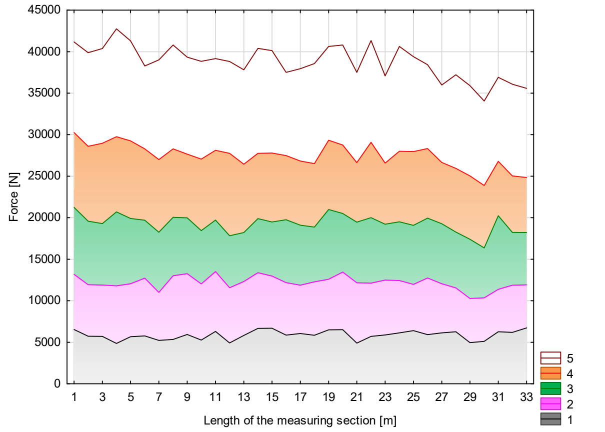

Fig. 5. The course of the working resistance force of the tool working at a depth of 0.35 m for individual variants of soil compaction

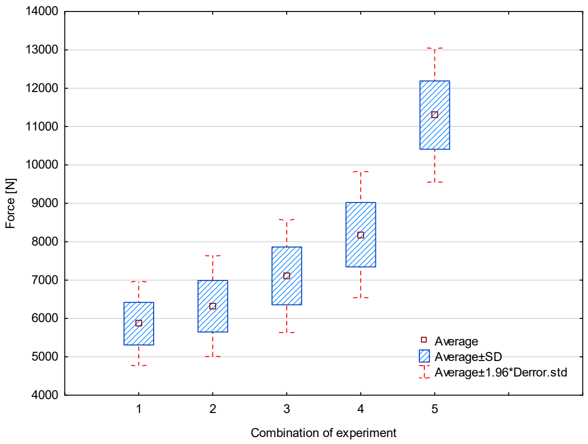

Fig. 6. Range of variation of the working resistance force of the tool working at the depth of 0.35 m for different variants of soil compaction

Five variants of ground compaction were used in the conducted tests, where the fifth was characterized by the highest value of drag force (see fig. 6). The analysis of the GPR signal amplitude characteristics focused on the two extreme cases, namely uncompacted and maximally compacted subsoil. Figure 7 shows the characteristics of the GPR signal amplitude along the length of the survey section before soil compaction, i.e. in the natural environment. There was a large variation in the amplitude of the GPR signal, which expressed by the coefficient of variation w was 27%. This was due to the inhomogeneity of the soil medium, which, however, is characteristic of natural conditions. Analyzing the working resistance of the tool (Fig.8), measured in the axis of symmetry of the trace of the GPR measurement, it was observed that the nature of the oscillation of the course of the force in the measurement section is similar to the nature of the oscillation of the GPR signal. However, it should be noted, the working resistance force of the tool was characterized by a much smaller coefficient of variation, which amounted to 11%. Comparing the course of the GPR signal amplitude (Fig.7) with the course of the tool's working resistance force, it was found that the lower amplitude of the GPR signal was characterized by places where the tool's working resistance force was higher. On the other hand, a larger signal amplitude was characterized by places where the value of the tool's working resistance force was smaller and therefore the soil medium was more heterogeneous in terms of compactness.

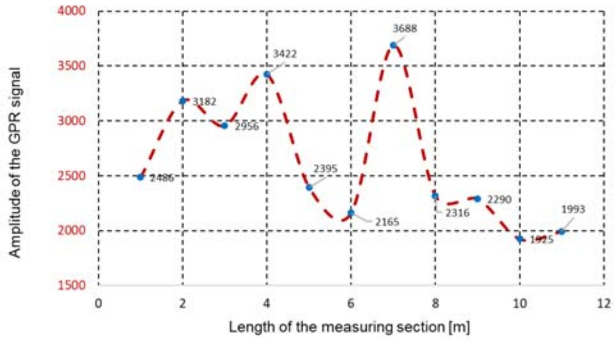

Fig. 7. The course of the GPR signal amplitude

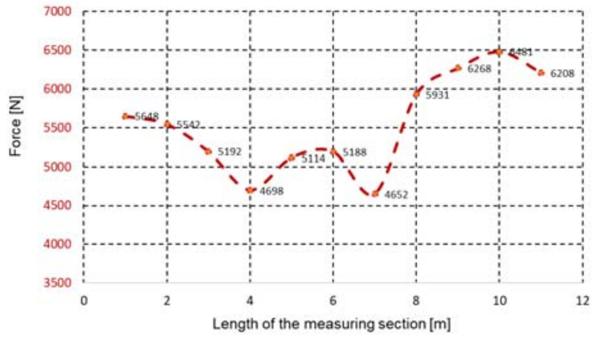

Fig. 8. The course of the tool operating resistance force in the case of non-compacted soil

Analyzing the characteristics of the amplitude of the GPR signal determined in the measurement section at the maximum compaction of the ground (Fig. 9), it was found that its range of variation was about 11%, which indicates a small variation in terms of the compactness of the studied medium. It was found that in the first part of the measurement section the amplitude of the GPR signal was higher compared to the final stage of the measurement.

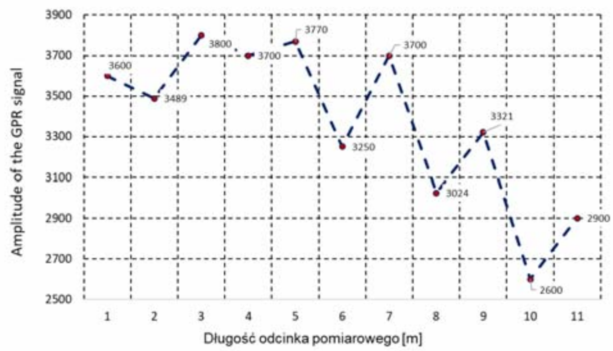

Fig. 9. The course of GPR signal amplitude

Comparing the characteristics of the waveform of the georadorned signal amplitude with the characteristics of the waveform of the tool's working resistance force (Figure 10), there was an even higher convergence of these curves than in the case of uncompacted soil. It should be noted that this convergence consisted of the fact that with a higher drag force, the value of the signal amplitude decreased, while with a lower tool working drag force, the value of the georadar signal amplitude increased.

In the extreme case, for the standard tool resistance force value of 11.873 kN, the value of the GPR signal amplitude was 2600 units, while already for the working resistance force of 10.701 kN, the GPR signal amplitude was 3700 units.

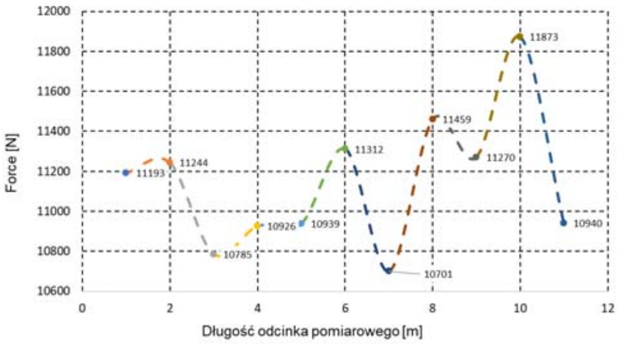

Fig. 10. The course of tool working resistance force in the case of compacted soil

Conclusion

It was observed that: (a) the number of passes less than four influences only the compaction of the topsoil up to the 0.2m level, while with a higher number of passes this influence is also transferred to the lower layers of the soil profile, (b) each method showed a more than 2-fold increase in compactness between the uncompacted soil profile and the soil profile after eight passes by the tractor wheels, (c) the confrontation of the results obtained by the GPR method and the values of the working resistance of the subsoiler measured by the strain gauge frame, showed their high convergence.

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REFERENCES

[1] Akinsunmade A Tomecka-Suchoń S Pysz P Karczewski J Juliszewski T Zagórda M Kiełbasa P 2020 Wykorzystanie metody konduktometrycznej i georadarowej do identyfikacji stopnia ugniecenia wierzchniej warstwy gruntu. Przegląd elektrotechniczny. ISSN 0033-2097, R. 96 NR 2/2020. S. 137-141.

[2] Juliszewski T Kiełbasa P Zagórda M Tomecka S Karczewski J Akinsunmade A 2019 Porównanie wyników badania zagęszczenia gleby uprawnej metodą penetrometryczną i georadarową. Przegląd Elektrotechniczny, ISSN 0033-2097, R. 95 NR 1/2019, s. 12-16.

[3] Akinsunmade A Tomecka-Suchoń S Pysz P Karczewski J Juliszewski T Zagórda M Kiełbasa P 2019 Assessment of mental load of an employee who operate a computer program supporting the didactic process. Applications of Electromagnetics in Modern Engineering and Medicine, PTZE 2019 8781724, pp. 9-12, ISBN: 978-838813100-4.

[4] Kiełbasa P Zagórda M Juliszewski T Akinsunmade A Tomecka S Karczewski J Pysz P 2021 Assessment of the possibility of using GPR to determine the working resistance force of tools for subsoil reclamation. Journal of Physics: Conference Series 1782 012013. PTZE2020. doi:10.1088/1742-6596/1782/1/012013.

[5] Kiełbasa P 2011 Zintegrowana metoda oceny nakładów energetycznych na uprawę podstawową w aspekcie mozaikowatości gleby. Rozprawy habilitacyjne Nr 33. Inżynieria Rolnicza 3 (128).

[6] Hanquet H Sirjacobs D Destain MF Frankinet M Verbrugge JC 2004 Analysis of soil variability measured with a soil strength sensor. Precision Agriculture 5, 3, 227-246.

[7] Van Bergeijk J Goense D Speelman L 2001 Soil tillage resistance as a tool to map soil type differences. J. agric. Engng Res. 79, 371-387.

[8] Van Bergeijk J Goense D Speelman L 2001 Soil tillage resistance as a tool to map soil type differences. J. agric. Engng Res. 79, 371-387.

[9] Budyn P Kiełbasa P Nykliński A 2003 Pomiar metodą tensometryczną oporów roboczych narzędzi i maszyn do uprawy i zbioru ziemniaków. Inżynieria Rolnicza. Nr 12(54), s. 57-65.

[10] Kiełbasa P Dróżdż T Zagórda M Kurpaska S Posyłek Z 2019 Wykorzystanie tensometrii oporowej do przestrzennej identyfikacji zróżnicowania wybranych właściwości gruntu. Przegląd Elektrotechniczny, ISSN 0033-2097, R. 95 NR 1/2019, s. 53-56.

[11] Szczęsny A., Korzeniewska E.: Selection of the method for the earthing resistance measurement, Przeglad Elektrotechniczny, 2018, 94(12), pp. 178–181

[12] Szczęsny A., Korzeniewska E.: Analysis of methods for measuring earth resistance and soil resistivity, 2018 Applications of Electromagnetics in Modern Techniques and Medicine, PTZE 2018, 2018, pp. 260–263, 8503241

[13] Karczewski J Ortyl Ł Pasternak M 2011 Zarys metody georadarowej, Wydanie drugie poprawione i rozszerzone, Uczelniane Wydawnictwo Naukowo-Dydaktyczne AGH Kraków ISBN 978-83-7464-422-8.

[14] Sikora R, Markiewicz P Reduction of the step voltages of MV/LV substation grounding system based on shaping electric field, Archives of Electrical Engineering, 2021, 70 (3), 601-613