EVALUATION OF SOIL PROPERTIES, FUEL CONSUMPTION AND GREENHOUSE GAS EMISSIONS OF A SITE-SPECIFIC TILLAGE METHOD

Simas SOKAS[1], Marius KAZLAUSKAS[2], Sidona BURAGIENĖ[3], Indrė BRUČIENĖ[1,2], Vilma NAUJOKIENĖ[1,2], Egidijus ŠARAUSKIS[1,2], Abdul Mounem MOUAZEN[1,3]

[1]Department of Agricultural Engineering and Safety, Faculty of Engineering, Agriculture Academy, Vytautas Magnus University, Studentu Str. 15A, Kaunas District, LT–53362 Akademija, Lithuania
[2]Bioeconomy Research Institute, Agriculture Academy, Vytautas Magnus University, Studentu Str. 11, Kaunas District, LT–53361 Akademija, Lithuania
[3]Department of Environment, Ghent University, Coupure Links 653, 9000 Gent, Belgium

Abstract
The main objective of this study was to investigate the changes in soil physical properties, fuel consumption and greenhouse gas emissions when using Variable Depth Tillage (VDT) compared to Uniform Depth Tillage (UDT). The experimental research was carried out in the autumn of 2024. A tine *cultivator was used at a depth of 15 cm for the UDT method, while this depth was varied between 10 and 25 cm for the VDT method. Changes in soil bulk density before and after tillage were analysed, and fuel consumption and greenhouse gas emissions were assessed for both tillage methods. The results showed that the use of VDT reduced the negative changes in fuel consumption and environmental impact without reducing the quality of the tillage, estimated as the physical properties of the soil.*

Key words: *Tillage depth, Diesel fuel, Environmental impact, Soil bulk density*

INTRODUCTION

Pre-seeding tillage can be divided into three broad groups: conventional tillage, conservation tillage and no-tillage. Both conventional and conservation tillage can be deep or shallow. Each type of tillage has its own advantages and disadvantages. Conventional tillage improves the soil surface for seed placement and germination, increases macropore volume for better air and water infiltration, and improves root development immediately after tillage. This type of tillage distributes organic matter through the layers, which can improve nutrient availability to plants *(Strunley et al., 2022)*. This conventional tillage method also facilitates mechanical weed and pest control *(Thakur and Sidar, 2017)*. However, in contrast to the positive aspects, traditional tillage results in higher fuel consumption, which increases greenhouse gas emissions and farming costs. In addition, long-term traditional tillage causes soil moisture loss and structural degradation due to the destruction of surface structures *(Veresoglou et al., 2023; Al-Wazzan et al., 2022)*. As an alternative to conventional tillage, conservation tillage *(Lithourgidis et al., 2009)*, strip tillage and no-tillage *(Saldukaitė-Sribike et al., 2022)* are widely used, reducing the risk of soil erosion, contributing to lower fuel costs and reducing the leaching of chemicals into groundwater *(Kumar et al., 2022)*. Due to high fuel consumption, negative soil and environmental impacts and other problematic factors, variable depth tillage *(VDT)* has become increasingly popular in recent years *(Meselhy, 2021; Wang et al., 2024; Tahmasebi et al., 2023)*. As technology improves, the efficiency of VDTs increases. To improve soil cultivation, depth control systems with sensors are being implemented more frequently *(Šarauskis et al., 2024)*. Soil properties are assessed using sensors such as penetrometers or by determining apparent electrical conductivity *(ECa)*. Then, variable-depth maps are produced to contribute to the efficient implementation of the site-specific tillage method *(Khalilian et al., 2002)*. Soil ECa maps allow precise identification of areas in a field where site-specific tillage is required, minimizing disturbance to other soil layers *(Corwin et al., 2003)*. According to Gorucu et al. *(2001)*, the need for deep tillage can be significantly reduced by varying soil compaction in the same field, the depth of the plough pan, which ranged from 10 to 25 cm in the authors' study. Whattoff et al. *(2017)* also found that it is possible to reduce tillage depth by up to 40% across the field *(Whattoff et al., 2017)*.
The main objective of this study was to investigate the changes in soil physical characteristics and fuel consumption when using variable depth tillage compared to uniform depth tillage.

MATERIALS AND METHODS

Short-term experimental research was conducted in the autumn of 2024 *(October)*. The research was carried out in the central part of Lithuania, in Kaunas district, on a 7-ha farmer's field at 55°09'20.0"N 23°53'32.4"E *(Figure 1a)*. Faba beans were grown as a pre-sowing crop. After harvest, the apparent electrical conductivity *(ECa)* of the entire field was determined using an EM38–MK2 electromagnetic induction soil scanner *(Geonics Ltd., Mississauga, ON, Canada)*. The exact coordinates of the data were determined using a Trimble EZ-Guide 250 *(Trimble Navigation Ltd., Alpharetta, USA)*. The data obtained were processed using soil and agricultural data management and analysis program SMS_v21_5 *(Soil Management System)*. The experimental field was then divided into zones. In order to assess soil variability and better show the differences between zones, 4 with different variable tillage depths *(VDT)* were selected for the research – 10, 14, 18; 25 cm, and using a uniform tillage depth *(UDT)*, as a control method – 15 cm. In the field *(Figure 1b)*, the VDT and UDT methods were carried out alternately in every second run.

Soil density tests were carried out before and after tillage. Soil samples were taken manually at 3 different depths – 0–10 cm, 10–20 cm and 20–30 cm. Samples were collected from 4 different zones: 10, 14, 18, 25 cm in 3 replicates, with samples from the UDT variety taken in a similar way.

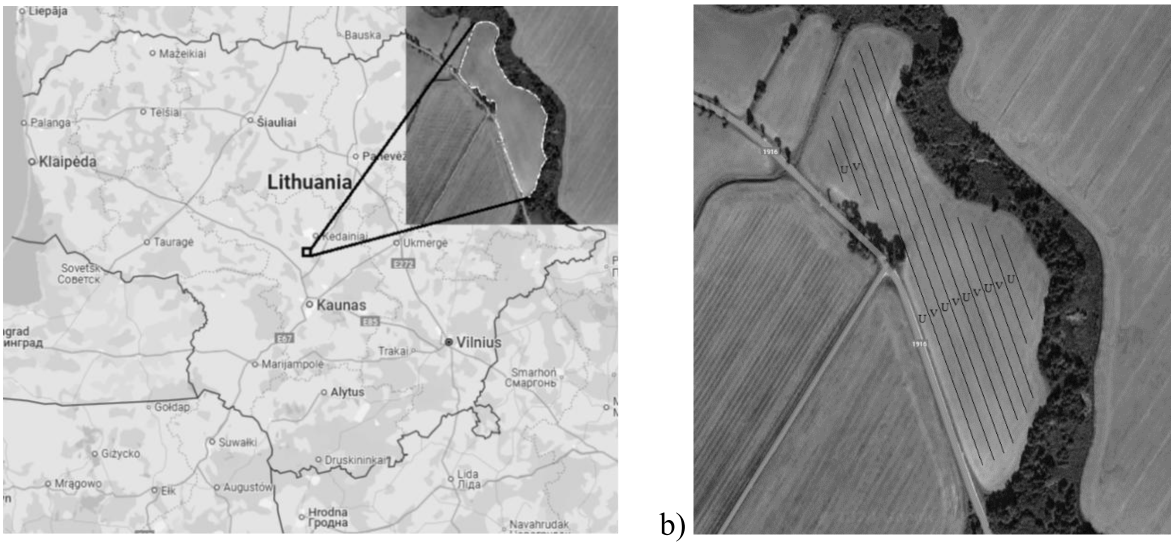
a) b)


Fig. 1 Field location maps: a) – Experimental site *(Lithuania M 1:1500,000; field: M 1:10.000)*; b) Field methods map: V – Variable Depth Tillage *(VDT)*, U – Uniform Depth Tillage *(UDT)* *(M 1:10,000)*

The Fendt 1050 Vario 380 kW tractor and the Väderstad TopDown 500 multi-purpose cultivator were used for tillage, which consisted of 12.5 cm tine discs and 27 cm tines, followed by levelling discs and U-shaped double compaction rollers. The effective working width of the implement was 4.80 m, the weight was 7000 kg and the working speed was 12 km h^{-1}. The working depth was changed using the Väderstad E-Services system. This system used Väderstad E-Control and allowed the soil to be worked according to a digital map via ISOBUS and the machine settings to be controlled automatically while driving according to the field map. E-Control was wirelessly connected to the implement, ensuring full access to its data flow and function control. The system controls and adjusts the tillage depth based on the readings from angle sensors installed on the tine harrow. The tractor's computer monitor displayed and recorded fuel consumption per hectare in real time. Using the GPS and a VDT map, the location and depth of tillage was visible on the monitor.

The experimental data were statistically processed using ANOVA two-factor with replication and one–factor analysis of variance methods. The significant influence of the VDT and UDT methods on soil density and fuel consumption was determined by calculating the least significant difference *($LSD_{0.05}$)* at the 95% level.

RESULTS AND DISCUSSION

After carrying out the measurements of apparent electrical conductivity *(ECa)*, a map was made showing the different tillage depth zones according to the different soil properties in the field *(Figure 2)*. The largest part was the 21 cm tillage zone with a total size of 1.216 ha and 14 cm *(1.193 ha)*, the smallest part was the 25 cm tillage zone – 0.871 ha.

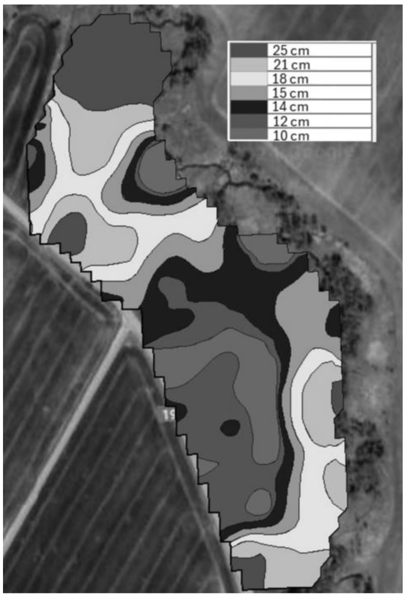
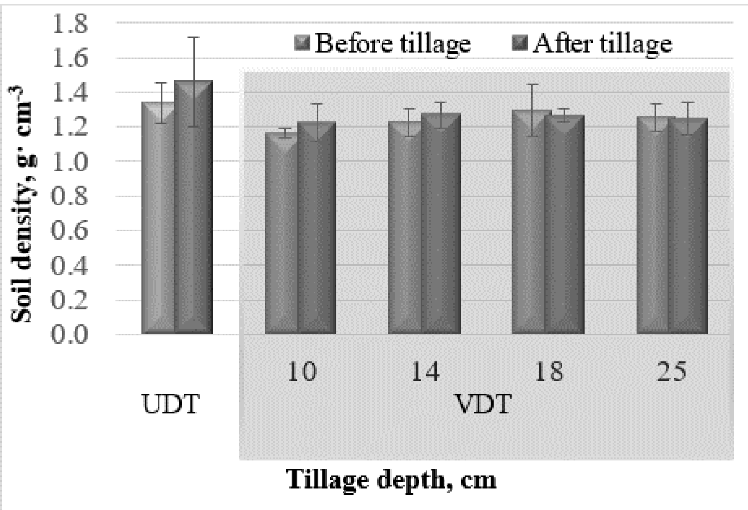


Fig. 2 Variable depth tillage map *(M 1:10,000)*

Soil density measurements showed different patterns of change depending on the depth of tillage and the method used. The control UDT method showed an increase in soil density of about 9% in the surface layer 0–10 cm *(Figure 3)* and a decrease of about 5% in the deepest layer 20–30 cm *(Figure 4)*. Using variable depth tillage *(VDT)*, in the same zone *(0–10 cm)*, a decrease in density was observed starting from 18 cm working depth, with a decrease of about 2 % and about 1 % respectively at 25 cm working depth. The VDT method results in a soil density approximately 5% lower than the UDT method. In the deep layer of 20–30 cm, the soil density also decreased with a change of about 8 % in the 18 and 25 cm deep VDT. In contrast, no significant differences between the methods were observed in the middle 10–20 cm depth.



ISBN 978-80-213-3541-7

Fig. 3 Change in soil density before and after application of UDT and VDT methods at a depth of 0–10 cm *(LSD0.05 = 0.07 g cm^{-3} (before)*; LSD0.05 = 0.10 g cm^{-3} *(after)*; LSD0.05 = 0.08 g cm^{-3} *(before and after)*)

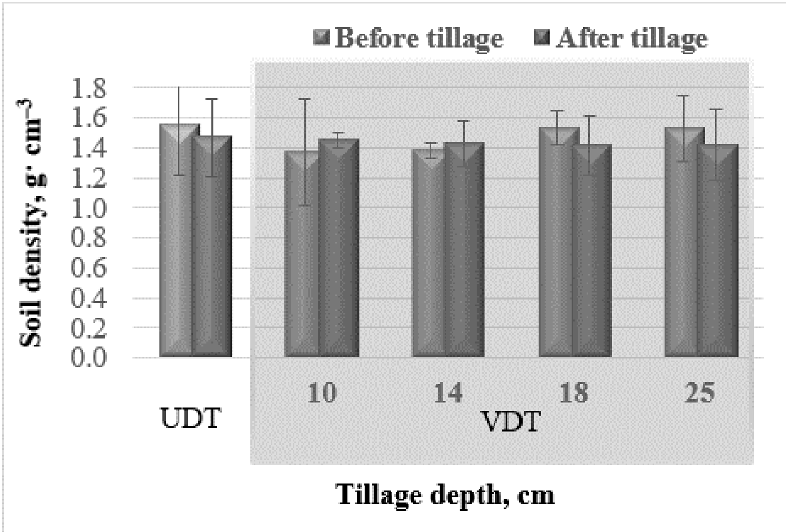


Fig. 4 Change in soil density before and after application of UDT and VDT methods at a depth of 20–30 cm *(LSD0.05 = 0.18 g cm^{-3} (before)*; LSD0.05 = 0.14 g cm^{-3} *(after)*; LSD0.05 = 0.15 g cm^{-3} *(before and after)*)

The fuel consumption per hectare was measured and presented in a fuel consumption bar chart *(Figure 5)*. Using Uniform Depth Tillage method, the average fuel consumption was 7.32 l ha^{-1}. For variable depth tillage, the fuel consumption at 10, 14, 18 and 25 cm depth was 5.27, 6.14, 8.98 and 19.18 l ha^{-1} respectively.

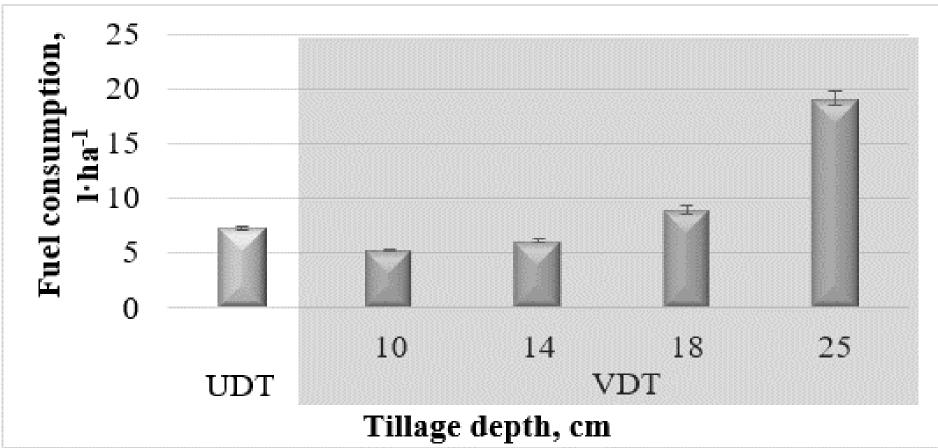


Fig. 5 Fuel consumption using UDT and VDT methods

The experimental research carried out in this study has shown that positive results can be achieved by using VDT. The trend of the change in soil density in both the lowest 0–10 cm and the deepest 20–30 cm layers was similar, when working at lower depths of 10–14 cm, the density after working increased, and when working at the deepest depths of 18–25 cm, the density decreased. These results were influenced by multi-purpose tine harrow design. As the working depth is increased, the position of the roller at the end of the implement is changed, resulting in the roller exerting more pressure on the soil at lower depths and less pressure at higher depths. Lower density can improve the penetration of plant

roots into deeper soil layers, water retention and the stability of soil aggregates *(Wells et al., 2005; Mahindru et al., 2024)*.
When comparing the results with other studies conducted by scientists, a similar trend was found. In a study conducted by Fox et al. *(2018)*, using the Clemson smart plough, which constantly measures the soil depth and adjusts the soil depth from 0 to 45 cm, fuel consumption was found to be 45% lower than when working with the UDT method, which had an average depth of 38 cm. In addition, the VDT method accurately eliminated soil depth and preserved the natural porosity and structure of the soil *(Fox et al., 2018)*. In a study by Meselhy et al. *(2021)*, variable depth tillage was applied to areas where the soil penetration resistance reached 2 MPa. They found that the VDT method could reduce fuel consumption by about 47% compared to uniform tillage at a depth of 35 cm. It also effectively broke up compacted soil layers that hindered root growth and crop productivity *(Meselhy, 2021)*.
Kim et al *(2006)* applied variable depth tillage to the cone index *(CI)* to determine soil strength and compaction layers. Based on CI values, 10 cm, 20 cm or 40 cm tillage depths were determined. The constant depth was set at 20 cm. The results showed that using VDT, about 75% of the study area required a shallower tillage depth than uniform tillage, which reduced energy requirements, resulting in a 28.4% reduction in fuel consumption, and soil layers with CI greater than 1.0 MPa reached less than 1.0 MPa after VDT *(Kim et al. 2006)*.
The results showed that fuel consumption during tillage depends not only on the tillage method and soil characteristics, but also on the terrain, especially differences in altitude. For example, in one of the variable depth tillage *(VDT)* zones with a working depth of 25 cm, a large part of the area was located on a slope, which resulted in significantly higher fuel consumption than in the other VDT zones *(18 cm)* and *(UDT)* zone *(15 cm)*.
Fuel consumption during tillage is strongly related to environmental impact. Considering that burning one liter of diesel fuel releases 2.76 kg CO_{2eq} into the environment *(Pishgar-Komleh et al., 2013)*, this means that in areas where greater depth is required, the environmental impact can increase significantly. Taking this dependency into account, the environmental impact in our study ranged from 14.54 to 52.94 kg CO_{2eq} for VDT and 20.20 kg CO_{2eq} for UDT.

CONCLUSIONS

Post-harvest and pre-sowing tillage methods have both positive and negative aspects in terms of their impact on soil, fuel consumption and the environment. Our mapping-based tillage studies showed that the average change in soil density in the upper soil layer was lower with VDT than with UDT. Similar trends were found in deeper soil layers. In addition to soil conservation, another important aspect of tillage change is the reduction in fuel consumption and associated greenhouse gas emissions. In summary, precise variable tillage can help to reduce fuel consumption, maintain a cleaner environment and reduce the cost of agricultural production.

ACKNOWLEDGMENT

This project has received funding from the Research Council of Lithuania *(LMTLT)*, agreement No S–MIP–24–120. Part of the funding was also received from the Ministry of Education, Science and Sports of the Republic of Lithuania and Research Council of Lithuania *(LMTLT)* under the Program ‘University Excellence Initiative’ Project ‘Development of the Bioeconomy Research Center of Excellence’ *(BioTEC)*, agreement No S–A–UEI–23–14.

REFERENCES

1. Al–Wazzan, F. A., & Muhammad, S. A. *(2022, July)*. Effects of conservation and conventional tillage on some soil hydraulic properties. In IOP Conference Series: Earth and Environmental Science *(Vol. 1060, No. 1, p. 012002)*. IOP Publishing.
2. Corwin, D. L., & Lesch, S. M. *(2005)*. Apparent soil electrical conductivity measurements in agriculture. Computers and electronics in agriculture, 46*(1–3)*, 11–43.
3. Fox, J. *(2018)*. Real-time, variable-depth tillage for managing soil compaction in cotton production *(Master's thesis, Clemson University)*.
4. Gorucu, S., Khalilian, A., Han, Y. J., Dodd, R. B., Wolak, F. J., & Keskin, M. *(1998)*.

Variable depth tillage based on geo–referenced soil compaction data in coastal plain region of South Carolina. In 2001 ASAE Annual Meeting *(p. 1)*. American Society of Agricultural and Biological Engineers.
5. Khalilian, A., Han, Y. J., Dodd, R. B., Sullivan, M. J., & Gorucu, S. *(2002, January)*. Technology for variable depth tillage in Coastal Plain soils. In Proc. 7th Conf. Beltwide Cotton, National Cotton Council, Memphis, TN.
6. Kim, L. Y., Cho, H. J., Chung, S. O., Park, W. Y., & Lee, K. S. *(2006)*. Determination of tillage depth based on physical properties of soil for rice production in Korea. Key Engineering Materials, 321, 1229–1232.
7. Kumar, S., Rani, V., Kumar, A., Pannu, R., & Mor, A. *(2022)*. Effect of Conventional Tillage and Zero Tillage on Different Soil and Yield Parameters. Journal of Agriculture Research and Technology, 47, 105–113
8. Lithourgidis, A. S., Damalas, C. A., & Eleftherohorinos, I. G. *(2009)*. Conservation tillage: A promising perspective for sustainable agriculture in Greece. Journal of Sustainable Agriculture, 33*(1)*, 85–95
9. Mahindru, V., Sharma, P., & Abrol, V. Efficiency of biochar with mineral fertilizers on soil properties and crop growth.
10. Meselhy, A. A. E. *(2021)*. Effect of variable–depth tillage system on energy requirements for tillage operation and productivity of desert soil. International Journal of Applied Agricultural Sciences, 7*(1)*, 38.
11. Pishgar–Komleh, S. H., Omid, M., & Heidari, M. D. *(2013)*. On the study of energy use and GHG *(greenhouse gas)* emissions in greenhouse cucumber production in Yazd province. Energy, 59, 63–71.
12. Saldukaitė–Sribikė, L., Šarauskis, E., Buragienė, S., Adamavičienė, A., Velička, R., Kriaučiūnienė, Z., & Savickas, D. *(2022)*. Effect of Tillage and sowing technologies nexus on winter wheat production in terms of yield, energy, and environment impact. Agronomy, 12*(11)*, 2713.
13. Strudley, M. W., Green, T. R., & Ascough II, J. C. *(2008)*. Tillage effects on soil hydraulic properties in space and time: State of the science. Soil and Tillage Research, 99*(1)*, 4–48.
14. Šarauskis, E., Sokas, S., & Rukaitė, J. *(2024)*. Variable Depth Tillage: Importance, Applicability, and Impact—An Overview. AgriEngineering, 6*(2)*, 1870–1885.
15. Tahmasebi, M., Gohari, M., Sharifi Malvajerdi, A., & Hedayatipour, A. *(2023)*. Development and field evaluation of a variable–depth tillage tool based on a horizontal pneumatic sensor measurement. Journal of Agricultural Machinery, 13*(1)*, 85.
16. Thakur, A. K., & Sidar, S. *(2017)*. Effect of Different Methods of Tillage and Conservation Farming on Nutrient Uptake, Available Nutrient in Soil and Balance Sheet of Nutrient in Finger Millet [Eleusine coracana *(L.)* Gaertn.] Under Rainfed Conditions. Int. J. Curr. Microbiol. App. Sci, 6*(12)*, 3670–3683.
17. Veresoglou, S. D., Chen, J., Du, X., Fu, Q., Geng, Q., Huang, C., ... & Zhang, R. *(2023)*. No tillage outperforms conventional tillage under arid conditions and following fertilization. Soil Ecology Letters, 5*(1)*, 137–141.
18. Wang, A., Ji, X., Zhu, Y., Wang, Q., Wei, X., & Zhang, S. *(2024)*. Tillage depth regulation system via depth measurement feedback and composite sliding mode control: A field comparison validation study. Measurement and Control, 57*(6)*, 685–702.
19. Wells, L. G., Stombaugh, T. S., & Shearer, S. A. *(2005)*. Crop yield response to precision deep tillage. Transactions of the ASAE, 48*(3)*, 895–901.
20. Whattoff, D., Mouazen, A., & Waine, T. *(2017)*. A multi sensor data fusion approach for creating variable depth tillage zones. Advances in Animal Biosciences, 8*(2)*, 461–465.

Corresponding author:
Simas Sokas, Ph.D. student, Vytautas Magnus University, Agriculture Academy, Department of Agricultural Engineering and Safety, Faculty of Engineering, Studentu str. 15A, LT–53362, Akademija, Kaunas Dist., Lithuania, phone: +37062943574, e–mail: simas.sokas@vdu.lt