Agronomy Research **12**(1), 187–196, 2014

Measurement of soil resistance by using a horizontal penetrometer working with the two-argument comparative method

F. Varga[1], Z. Tkáč[1], T. Šima[2,*], Ľ. Hujo[1], J. Kosiba[1] and D. Uhrinová[1]

[1]Slovak University of Agriculture in Nitra, Faculty of Engineering, Department of Transport and Handling, Tr. A. Hlinku 2, 949 76 Nitra, Slovak Republic
[2]Slovak University of Agriculture in Nitra, Faculty of Engineering, Department of Machines and Production Systems, Tr. A. Hlinku 2, 94976 Nitra, Slovak Republic; *Correspondent author: tomasko.sima@gmail.com

Abstract. Currently, the interest in land is high and is increased by in relation to the increasing need for livelihood of the population. Therefore, the need for land use to increase its potential production while ensuring a sustained recovery of agricultural systems still exists. The aim of this publication is to test the measurement of the soil resistance impact at different levels of humidity using a newly designed type of a measuring device – a horizontal penetrometer. The measurements were carried out under field conditions by average soil moisture of 8.47% and 14.24%, on the basis of the two parameters comparative method by using a horizontal penetrometer. The proposed measuring device measured the soil resistance in the tire track and outside of the track after five passages of the tractor. Measuring and recording devices to capture the measured values were also designed. From the results, we can indicate that the soil resistance after each passage increases and we also observed that after the first passage, the soil resistance increased by about 48.1% compared to the initial soil resistance. The average soil bulk density corresponds proportionally with the soil resistance increases in both the absolute and relative terms, depending on the number of tractor passages. It is possible to conclude that the newly designed measuring device is working properly and can be used for all types of tractors equipped with a three-point hitch with the tire tread width of 1,000–2,000 mm. The measurement results will be utilized in mapping of the actual conditions of soil environment.

Key words: soil resistance measurement, soil compaction, bulk resistance.

INTRODUCTION

Soil strength is defined as the resistance which has to be overcome to obtain a given soil deformation. In cultivation operations, high soil strength can be favourable or unfavourable according to the objectives. It is favourable to enable traffic, because it raises the soil bearing capacity, but is unfavourable to soil tillage ,since it increases the draft, making it more difficult to create an optimal soil structure, disturbs seeds germination and root growth (Sirjacobs, et al., 2002). Nowadays, all technological operations in crop production are performed with the use of agricultural machines. This has got plenty of pros such as the low cost per hectare, but one of main cons is the soil compaction side effect. The soil compaction caused by agricultural machinery is an important factor which affects carbon dioxide (Šima & Dubeňová, 2013) and nitrous oxide (Khaledian et al., 2012; Šima et al., 2013) flux from soils and therefore has a significant environmental effect. The machines in use today are larger, and heavier but they also have more power and are more effective (Varga et al., 2009, Varga et al., 2010). They maintain longer contact with soil than ever before. This effects the soil density. Soil compaction results in changes in water and air movement and also affects root growth. Finally, it also affects the yield crop (Savin et al, 2009).

Soil mechanical resistance (SMR) to penetration varies in time and space (Krištof et al, 2010). Soil mechanical resistance is strongly influenced by water content or water potential and the temporal variation in water content through the growing season accounts for part of the temporal variation in SMR (To & Kay, 2005). The functional relation between SMR and soil water content or potential is referred to as the SMR curve. Measurements on soil cores obtained from the depth of 5 to 7.5 cm across a landscape under contrasting tillage practices have shown that the SMR curve varies with soil characteristics such as texture, organic carbon (OC) content and bulk density (D_b) (Da Silva & Kay, 1997).

With reference to the definitions used in soil resistance, it is clear that many of them have focused on soil bulk density. Accordingly, many researchers have used bulk density to measure soil resistance (Kamgar & Minaei, 2001, Chorom & Sadeghzade, 2005, Javadi & Spoor, 2006). The problem is that the developed penetrometers can be used only for local vertical measurements. From a practical point of view, it appears to be the best and the easiest two-argument comparative method to obtain objective results. This method involves continuous measurement of two parameters. On this principle, a measuring device was developed with the two-argument comparative method at the Department of Transport and Handling. The test measuring device was designed according to the works published by Hoffmann et al., (2012), Hoffmann et al. (2013), Chyba et al. (2013) and Šarauskis et al. (2013).

MATERIAL AND METHODS

As a result of soil compaction, the soil resistance increases, therefore it is possible to use this phenomenon to experimentally measure the degree of soil compaction. The penetrometer method is based on this. So, to use a knife jointer to measure soil resistance, we consider it as an experimental method to detect the degree of soil compaction for the traverse mechanism of tractors. As follows, there is a need to theoretically analyze the principle of soil resistance measuring by a knife jointer. Fig. 1 shows the main dimensions of the knife jointer in depth for the particular task.

The total length of the knife jointer L is given by:

$$L = \frac{H + h}{\cos\beta} + \Delta L \qquad [\text{m}] \qquad (1)$$

where: H – frame height from tip of jointer; h – thickness of the longitudinal beam; ΔL – addition to attaching (or wearing / 100 mm); β – angle of jointer.

The length of blade is determined according to:

$$L_1 = \frac{a}{\cos\beta} + \Delta L_1 \qquad [m] \qquad (2)$$

where: a – working depth; ΔL_1 – addition with respect to the terrain roughness (100 mm).

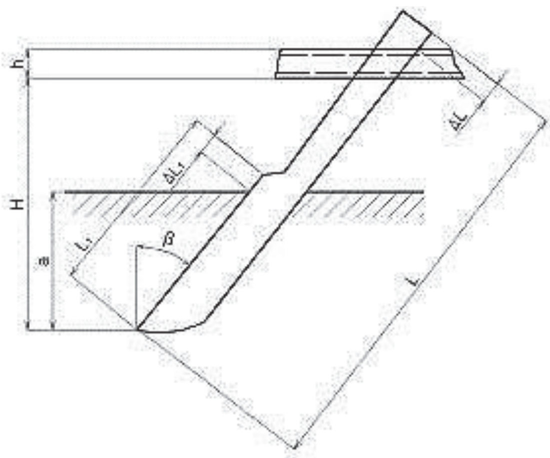

Figure 1. The main dimensions of the knife jointer.

The jointer blade is constructed relative to the vertical axis at an angle β. It depends on the value of this angle whether the slitting plant roots will be sliding along the jointer blade or not. The value of the angle β also determines the recessing ability of jointer (see Fig. 2).

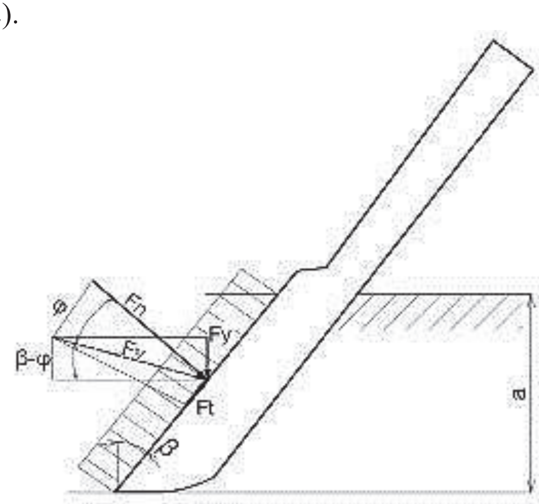

Figure 2. Determining the angle of the jointer blade.

Based on the force relationships solution of the jointer, we assume that the blade of the jointer operates under constant load over the entire length. This load is defined by the centric force F_n, which is calculated by:

$$F_n = \frac{q \cdot a}{\cos \beta} \quad [N] \quad (3)$$

q – specific load on the blade.

The specific load on the coulters q depends on the physical condition of the soil and on the degree of its compaction but also on the state of the blade. The force F_n also causes frictional force F_t, which is given by:

$$F_t = F \ tg\varphi \quad [N] \quad (4)$$

φ – friction angle.

The resultant force of these two forces is the force F_v and is determined according to:

$$F_v = \sqrt{F_n^2 + F^2} = F_n \sqrt{1 + tg^2 \varphi} \quad [N] \quad (5)$$

The jointer is pushed into to the land by the vertical component F_y of the resultant force F_v which is calculated according to:

$$F_y = F_v \cdot \sin(\beta - \varphi) \quad [N] \quad (6)$$

Then it substitutes to:

$$F_y = q \cdot a \left(tg\beta - tg\varphi \right) \quad (7)$$

It follows from the last formula that the vertical component of the resultant force that causes recessing of the jointer is growing proportionally with the working depth a. For the jointer to recesses into the soil, it must be $F_y > 0$. This will meet the requirement only if:

$$tg\beta - tg\varphi > 0 \quad (8)$$

Therefore applies to:

$$\beta > \varphi \quad (9)$$

For the jointer to recess easily, it must be set at greater angle β than the friction angle φ between the steel and the soil. The greatest value of the friction angle is $\varphi = 40°$, which is the value of heavy, wet soil. Therefore, for the jointer to recess under all conditions, there must be $\beta > 40°$. On the basis of this theoretical analysis of force relationships, it applies that soil resistance can be continuously measured on that basis, provided that the force F_n acting on the blade of the jointer will be appropriately registered and measured at work or by moving of the jointer in the soil. On this principle, the measuring device with the two-argument comparative method works.

The methods for measuring soil compaction are based on the principle of measuring the force by inserting an unknown object with a defined geometric shape into the soil. The result shows as the dependency between the force needed to push the object into the soil and the corresponding depth. However, these dependencies have only local significance and cannot be used to establish global soil compaction in a given locality. The developed penetrometers can also only be used for local vertical measurements. From a practical point of view, it appears to be the best and the easiest two-argument comparative method to obtain objective results. This method involves continuous measurement of two parameters. The first parameter characterizes the state of the soil before the negative impact of technology on the soil and the second reflects that negative impact of technology on the soil compaction. Based on this principle, a measuring device was developed with the two-argument comparative method at the Department of Transport and Handling (see Fig. 3), which was really practically tested there.

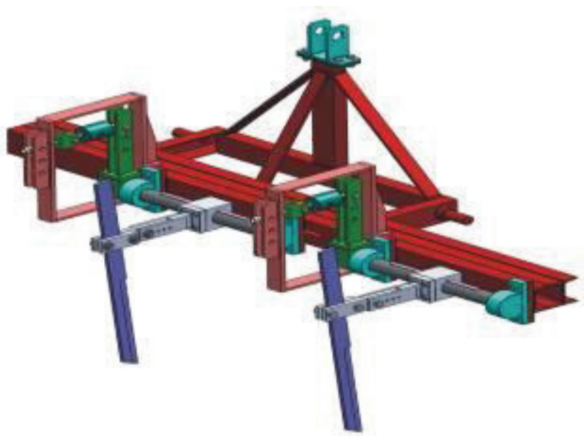

Figure 3. Measuring device with the two-argument comparative method.

The device is attached to the three-point linkage of the tractor with a supporting frame. The beam is welded from three U profiles and it forms the carrying plate of the measuring device. It is fixed to the support frame by two fixing bolts and is adjustable in four positions. This adjustability enables to change the position of the jointers in the wheel track or outside of the wheel track by the tire tread width. There are two shafts pivotally attached to the beam by the bearing housings. On each shaft, there is a jointed blade attached through the hub and shoe. Around the pin, there are pivotally attached shoes with the blade jointer (see Fig. 4).

If the jointer is obstructed, the fuses will be cut so the system is protected against overloading. The principle of the device consists of the fact that in the soil resistance measurement with using jointers, the force applied to the jointers relative to the axis of the shaft causes torque that is transferred through the short arm to the load cells power sensors. The data from the sensors are processed in other measuring and recording devices.

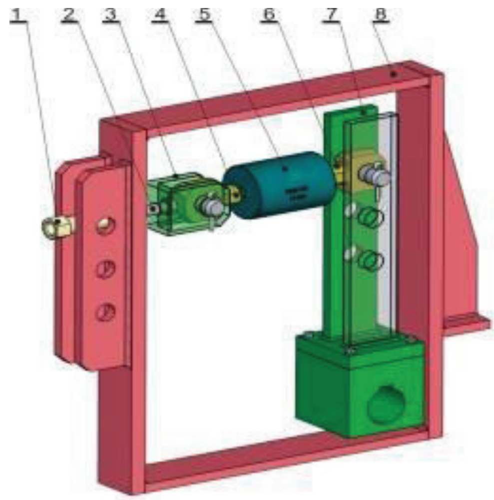

Figure 4. The frame to attach the power sensor: 1 – set screw; 2 – bolt M 12 x 70 STN 02 1101; 3 – sensor bracket; 4, 6 – attachment to the power sensor EMS 150 – 10 kN; 5 – load cells power sensor EMS 150 – 10 kN; 7 – arm, 8 – frame.

The soil resistance was continuously measured in the tire track and outside of the track of a tractor of the type New Holland T6070. The measured parameters – soil resistance (kN) and time (s) – were recorded by using the proposed device via load cells power sensors and a handheld digital device HYDAC 2020. The measurements were performed by five passages in the tractor. The soil moisture was 8.47% and 14.24%, the measuring depth 15 cm and tractor speed 3.6 km h^{-1}. The soil bulk density and soil moisture were determined according to the standard norm ISO 11274:1998. All data were processed and graphically illustrated and measurements were performed at two different soil moistures. The land on which the experimental measurements were performed was on school land in Kolíňany, Slovakia. The land was measured after cultivation of winter oilseed rape and spring barley, modified by disks and stubble plough. The type of the soil was brown soil. For measurements, a tractor of the type New Holland T6070 was used, the weight of the tractor with a measuring device: the total of 6,890 kg, 2,860 kg – front axle and rear axle – 4,030 kg. The type of the rear tires used: Firestone 600/65 R38, Radial 9000, pressure 2.5 bar (wheel rim D = 1,000); and the type of front tires: Firestone 480/65 R28, Radial 9000.

RESULTS AND DISCUSION

The results of the soil resistance measurement after multiple passages of a tractor which were recorded by the unit HYDAC 2020 and processed in the PC are shown in the form of a graph in Fig. 5.

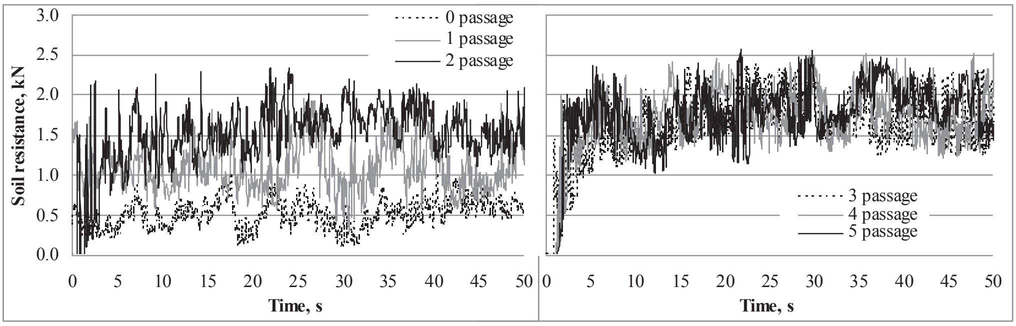

Figure 5. The soil resistance values in the track after each passage (soil moisture 8.47%).

The results of the soil resistance measurement after multiple passages of a tractor at the soil moisture of 14.24% which were recorded and processed in the PC are shown in Fig. 6.

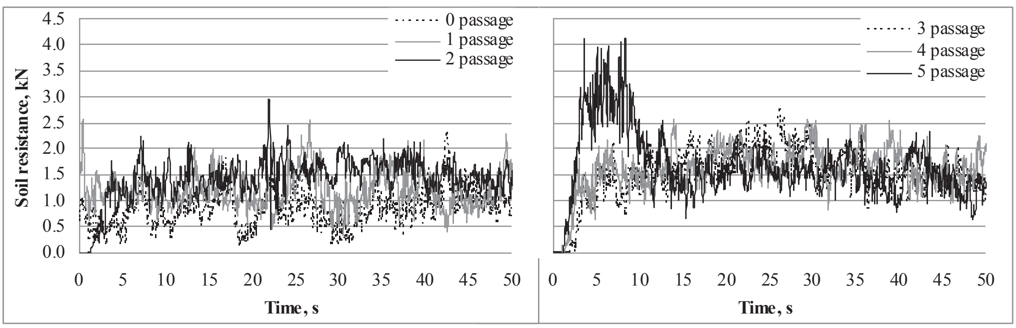

Figure 6. The soil resistance values in the track after each passage (soil moisture 14.24%).

Based on the measurements visible in the graphs, we can compare the values of soil resistance in the track on each passage at different levels of humidity as follows – see Fig. 7. Fig. 8 shows a comparison of the average soil bulk density at different levels of humidity.

The proposed measuring device measured the soil resistance in the tire track and outside of the track after multiple passages at two soil moistures. At the same time, the average soil bulk density and its change after multiple passages of a tractor was measured. As individual graphs show, the soil resistance after each passage increases and it was also observed that after the first passage, the soil resistance increased about 48.1% compared to the initial soil resistance.

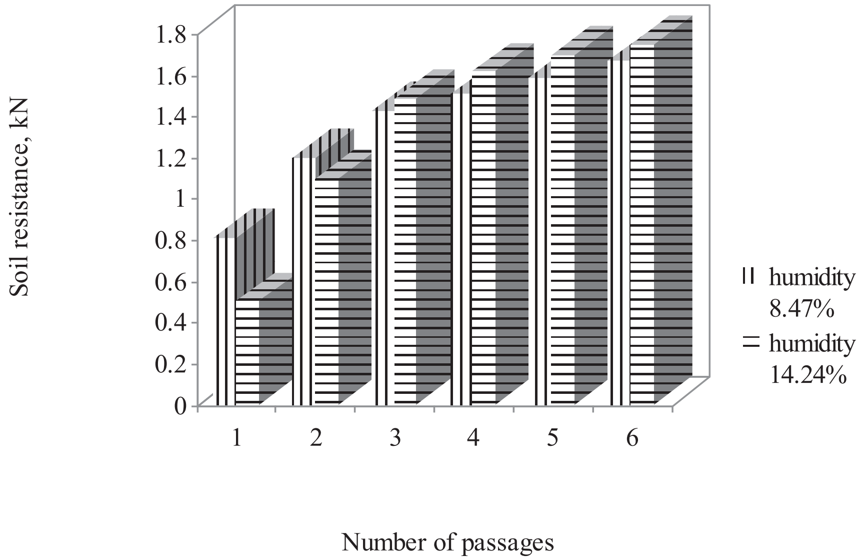

Figure 7. The values of the soil resistance in the track after each passage at different levels of moisture.

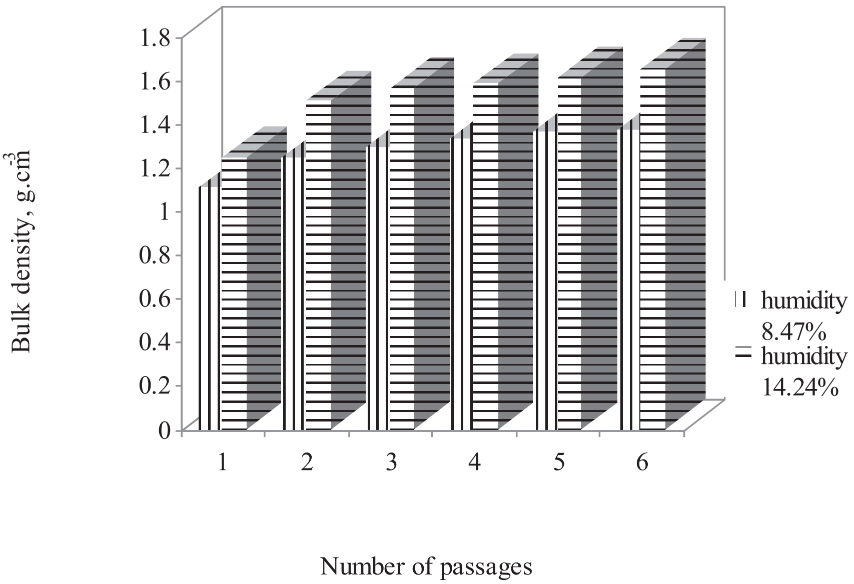

Figure 8. The soil bulk density in the track after each passage at different levels of moisture.

It also increased by about 27.2% after the second passage, about 11.1% after the third passage, about 9.9% after the fourth passage and about 9.9% after the fifth passage compared to the previous soil resistance. The average soil bulk density corresponds to the soil resistance increases proportionally in both absolute and relative terms, depending on the number of tractor passages. The percentage is about 12.6%

after the first passage, about 4.5% after the second passage, about 3.6% after the third passage, about 2.7% after the fourth passage about and about 0.9% after the fifth passage over the previous passage. The second measurements were made under changed humidity conditions from 8.47% to 14.24% and correspond with the results obtained in the first experiment. It is also evident from the graph that the largest increase in soil resistance is after the first passage of the tractor at both values of humidity. Also, the largest increase in the soil bulk density is after the first passage of tractor. In both of these measurements, the higher values of soil bulk density at higher humidity were also measured. If the soil moisture is 8.47%, the land is quite dry which is also reflected in the results of the measurement. Therefore, it can be concluded that since the increase of soil resistance and soil bulk density is influenced by soil moisture and by elevated humidity, the movement of agricultural equipment on the land should be restricted to limit its oppression, thereby reducing its fertility.

CONCLUSIONS

In evaluation of the results, two perspectives are taken into account. First, a measuring device was designed and built for measuring soil resistance with the two-argument comparative method, and simultaneously, measuring and recording devices were designed to capture and record the measured values. The test results showed that the proposed device meets the requirements placed on it and can be used for all types of tractors equipped with a three-point hitch with a tire tread width of 1,000–2,000 mm.

Because of the increasing efforts to accelerate the processing of a large number of measurements, the use of automated penetration systems together with location of the measurements with GPS are increasingly used. This allows us to quickly map the actual conditions of soil environment and to incorporate them into soil maps.

ACKONWLEDGEMENTS. This contribution was realized under the agreement of the solution of the grant project VEGA 1/0857/12 'Reduction of unfavorable impacts of agricultural and transport machinery on environment'.

REFERENCES

Da Silva, A.P. & Kay, B.D. 1997. Estimating the least limiting water range of soils from properties and management. *Soil Science Society of America Journal* **61**, 877–883.

Hoffmann, D., Heřmánek, P., Rybka, A. & Honzík, I. 2012. Evaluation of interaxle carrier and design of mechanical pruner for low trellis system. *Scientia Agriculturae Bohemica* **43**(1), 8–13.

Hoffmann, D., Heřmánek, P., Rybka, A. & Honzík, I. 2013. Design a drive for interaxle mechanical cutter used in low trellises. *Agronomy Research* **11**(1), 39–46.

Chorom, M. & Sadeghzade, F. 2005. The effect of soil compaction on movement, phosphorus and potassium in soil columns. *The Scientific Journal of Agriculture* **27**(2), 139–153.

Chyba, J., Kroulík, M., Lev, J. & Kumhála, F. 2013. Influence of soil cultivation and farm machinery passes on water preferential flow using brilliant blue dye tracer. *Agronomy Research* **11**(1), 25–30.

Javadi, A. & Spoor, G. 2006. The effect of spacing in dual wheel arrangements on surface load support and soil compaction. *Journal of Agricultural Science and Technology* **8**(2), 119–131.

Kamgar, S. & Minaei, S. 2001. Evaluation of the influence of a few effective parameters on soil compaction caused by disk and moaldboard plows. *Agricultural Sciences* **6**(4), 5–19.

Khaledian, M.R., Mailhol, J.C. & Ruelle, P. 2012. Impacts of direct seeding into mulch on the CO_2 mitigation. *Agronomy Research* **10**, 303–310.

Krištof, K., Boďo, T. & Misiewicz, P. 2010. Influence of work implements on selected soil properties. *Technics in agrisector technologies 2010: proceedings of scientific works*, Nitra, november 2010. pp. 86–92.

To, J. & Kay, B.D. 2005. Variation in penetrometer resistance with soil properties: the contribution of effective stress and implications for pedotransfer functions. *Geoderma* **126**(3–4), 261–276.

Savin, L., Nikolić, R., Simikić, M., Furman, T., Tomić, M., Gligorić, R., Jarak, M., Durić, S., Sekulić, P. & Vasin, J. 2009. The influence of soil compaction on changes in soil and sunflower yield. *Savremena poljoprivredna tehnika* **35**(1–2), 26–32.

Sirjacobs, D., Hanquet, B., Lebeau, F. & Destain, M.F. 2002. On-line soil mechanical resistance mapping and correlation with soil physical properties for precision agriculture. *Soil and Tillage Research* **64**(3–4), 231–242.

Šarauskis, E., Romaneckas, K., Sakalaukas, A., Vaiciukevičius, E., Vaitauskiene, K., Karayel, D. & Petrauskas, R. 2013. Theoretical analysis of interaction of disc coulters and straw residues under no-tillage conditions. *Agronomy Research* **11**, 89–96.

Šima, T. & Dubeňová, M. 2013. Effect of crop residues on CO_2 flux in the CTF system during soil tillage by a disc harrow Lemken Rubin 9. *Res. Agr. Eng.* **59**, Special Issue, S15–S21.

Šima, T., Nozdrovický, L., Dubeňová, M., Krištof, K. & Krupička, J. 2013. Effect of crop residues on nitrous oxide flux in the controlled traffic farming system during the soil tillage by LEMKEN Rubin 9 disc harrow. *Agronomy Research* **11**, 103–110.

Varga, F., Jablonický, J., Müllerová, D. & Žikla, A. 2009. Influence of soil resistance on ploughing depth. *Traktori i pogonske mašine* **14**(1), 49–58.

Varga, F., Abrahám, R., Jablonický, J., Boďo, T. & Chrastina, J. 2010. Measurement of soil compaction with horizontal and vertical cone penetrometer. *Savremena poljoprivredna tehnika* **36**(3), 247–255.