INFLUENCE OF SOIL HARDNESS ON TRACTION FORCE OF DIFFERENT DESIGN COULTERS

Egidijus Sarauskis, Kestutis Romaneckas, Kristina Vaitauskiene, Antanas Sakalauskas, Edvardas Vaiciukevicius, Remigijus Petrauskas
Aleksandras Stulginskis University, Lithuania
egidijus.sarauskis@asu.lt, kestas.romaneckas@asu.lt, kristinaa19@gmail.com

Abstract. No-tillage technologies have been developed in the world and in Lithuania at the same time, because of economical and environmentally-friendly advantages. However, the sowing into no-plowing and completely undeveloped soils is more complex because plant residues prevent in the soil. Using no-tillage technology, the soil surface is usually much harder if compared with tillage soils. Therefore, the sowing coulter in no-tillage soils has more difficulty in penetrating into the soil and ensuring the required sowing depth. The soil hardness also has an unavoidable influence on tillage and traction forces of sowing coulters. The research aim is to determine the influence of soil hardness of different tillage on the traction force of various coulters. The tests were carried out in three variants. In the first version the soil surface was loosened by the vertical rotary cultivator, in the second version it was loosened by the vertical rotary cultivator and compressed two times by a plain roller of 1000 kg mass, in the third version it was compressed six times by the plain roller. The tests were carried out with two different coulters: hob and complex, which consisted of two disc and hob coulters. The coulters were pulled at the speed of 1.39 $m \cdot s^{-1}$, the traction force was measured by six sensors, three of which measured the horizontal force, two measured the vertical force and one measured the lateral force. The tests have shown that to pull the complex coulter less traction force is required than to pull the hob coulter independent on the soil hardness.

Keywords: traction force, soil hardness, coulters, no-tillage soil.

Introduction

The recent increase in fuel prices is becoming more and more important for reducing the energy consumption problem. In order to minimize energy consuption new tillage technologies are developed that reduce the number of passes through the soil, and use less energy receptive working parts. When sowing into no-tillage soils the greatest forces affect the sowing coulter because the hard soil surface resists to the coulter penetration into the soil and the traction.

Sowing coulters of each type have benefits and limitations. However, under different conditions their working parts do not always satisfy the agrotechnical requirements of the sowing quality. Hoards of straw and soil have more negative influence on the sowing quality of hob coulters compared with disc coulters. Moist and less fine-cut straw especially prevent to reach good quality results [1; 2].

The insertion conditions of agricultural plant seeds into no-tillage soil are more complicated compared to routine sowing into well prepared soil. It is difficult to make a clean furrow of even depth where the inserted plant seeds would ensure good growth conditions when the soil surface is hard and overlaid with plant residues [3]. When sowing into no-tillage soil, the discs of drill coulters penetrate worse than into no-plowing or minimum tillage soil due to greater soil hardness. The disc drills of greater mass are designed in order to ensure the established sowing depth. Therefore, the part of the gravity force of the sowing coulter increases and it easier penetrates into the soil [4].

The horizontal resistance force of the sowing coulter is the most important from the energy consumption point of view, because it makes 80-90 % of resistance force of all the operating parts of the disc drill. This force depends on the coulter design and the soil properties [5].

The sowing coulters are also influenced by the vertical resistance force. The ratio of the disc coulter vertical resistance force with horizontal force can amount to two or even more times in the hard soils [6]. The vertical force influencing the shank coultes and sagittal coulters depends on their angle position, operating depth, soil properties and speed [7; 8]. Sowing coulters are different from the point of view of soil loosening and energy consumption. This is especially important when sowing into the hard, unloosened soil when the energy demand is much greater than when sowing into the loosened soil [9; 10].

The relative soil resistance of hard loam soil is the least when the soil moisture content is 16.4-23.5 %, and the soil hardness decreases from 2700 kPa to 800 kPa when the soil moisture content changes from 10 % to 25 %. The soil resistance increases about 1.4 times when the moisture content changes from 25 % to 28 % [10].

According to Germanas [11], the change of the angle position of the disc sowing coulter in the movement direction has the most impact on the horizontal resistance force. Changing this angle from 0° to 10°, the resistance force increases from 1.28 to 1.66 times in the light loam soil, depending on the straw number and length.

Germanas [9] has compared the sagittal, single-disc and two-disc sowing coulters in the working depth of 30-50 mm and found that the least traction force is needed for the sagittal coulter during loosening of loam soil. This force decreases for the single-disc coulter when its turning angle is increased in the movement direction. The least traction force of the single-disc coulter when it is turned at the angle of 5º is (124.1 N), the largest traction force of the two-disc coulter is (176.2 N).

Povilaitis and Germanas [12] have investigated the resistance to traction of hob and sagittal sowing coulters in sandy loam (the hardness of 160-164 kPa) and loam (the hardness of 185-250 kPa) soils. They have shown that the drag resistance forces of the hob coulter are relatively low at the sowing depth of 2-3 cm in the loosened soil. The horizontal resistance force of the coulter in the sandy loam soil is by 1.3 time less than in the loam soil. When sowing in the depth of 4-6 cm the horizontal resistance force is by 2-3 times greater than when sowing in the depth of 2-3 cm in sandy loam and loam soils.

Šarauskis [13] states that to pull the direct-sowing coulter in the soil of different hardness one needs from 0.028 to 0.109 kN less force if compared with the routine coulter. Increasing the soil hardness from 0.4 to 0.88 MPa, the traction force of the direct-sowing coulter increases by 0.086 kN. When the speed of the direct-sowing coulter is varied from 1.39 $m \cdot s^{-1}$ to 2.50 $m \cdot s^{-1}$, and the soil hardness is 0.4 MPa, the traction force increases by 0.047 kN, and when the soil hardness is 0.88 MPa, the traction force increases by 0.017 kN.

Ranta etc. [14] have investigated flat and wavy sowing disc coulters with different wave intervals. They have shown that the vertical and horizontal traction forces are more stable for the disc coulter with 26 waves than for the flat coulter and the disc coulter with 14 waves when the operation speeds were 3 $km \cdot h^{-1}$ and 11 $km \cdot h^{-1}$.

Celik and Raper [15] have stated that the tillage disc coulter with five blades needs significantly less force (from 10 to 68 %) in the depth of 25 and 38 cm than the coulter without blades and shank type coulter.

The research aim is to determine the influence of the soil hardness of different tillage on the traction force of various coulters.

Materials and methods

The tests were carried out in the soil bin that is 46 m long, 5 m wide and 1.2 m deep. The composition of the soil in the bin was 72 % of sand, 16 % of loam, 12 % of clay. The soil hardness was changed three times: in the first version the soil surface was loosened by 1.5 m width vertical-rotar cultivator, in the second version the soil suface was compacted two times by 1.3 m width plain roller the mass of which was 1000 kg, in the third version the soil surface was compressed six times by the plain roller. The soil hardness was measured with manual penetrometer with time indicator (the value of one scale division was 6894.7 Pa), the engagement of soil clods was measured with a gauge with the blade type propeller tip (the value of one scale division was 0.04788 kPa), moisture was measured with the volume moisture meter “TRIME-FM”.

The researchers used the hob and complex coulters adapted for sugar beet precision sowing. The complex coulter consisted of two 380 mm diameter disc knifes with notches, installed at the angle of 15º and the hob coulter installed between the discs, which went deep into the soil at the angle of 105º, moreover, it made the furrow of 30 mm depth (Fig. 1). The minimum interval between the disc knifes was 6 mm. The right disc knife had 11 semi-circular notches, the left disc knife had 15 semi-circular notches. The left-side disc knife was pushed in respect to the right-side disc knife by 15 mm forward in the driving direction. The disc knives went into the soil at the depth of 25 mm.

The coulter resistance force to traction was measured with a traction force meter that consisted of the frame of two parts with six measuring sensors, three of which recorded the horizontal, two vertical and one lateral traction force. The traction forces meter was attached between the self-propelled machine and one section of the frame of the precision sowing drill. The speed was measured by the wheel rotating near the disc drill. The measurement time is 10 s, ten traction forces and speed values were measured during one second. The sowing coulters were pulled at the speed of 1.39 $m \cdot s^{-1}$. The sensor data were collected and then processed by a computer „MGCPANEN" program. The tests were carried out in three replications, the experimental data were processed using mathematical statistical methods.

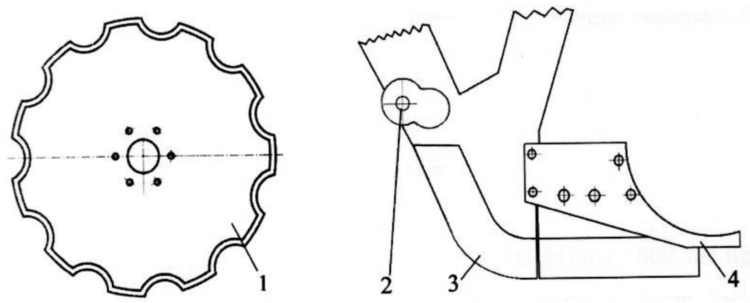

Fig. 1. **Complex sowing coulter parts:** 1 – disc knife with notched blades; 2 – mounting place of the disc knife; 3 – hob coulter with extended hob; 4 – mount of sowing apparatus

Results and discussion

The research has shown that the hardness of soil was from 0.006 MPa to 0.044 MPa in the first variant (the soil surface was loosened), in the second variant (the soil surface was two times compressed) the soil hardness was about 20 times greater than in the first variant (from 0.227 MPa to 0.493 MPa) like in no-tillage light loam soil (Table 1). The soil hardness in the third variant (the soil surface was compressed six times) was greater about two times than in the second variant and the soil hardness was like in the medium hardness no-tillage loam soil (from 0.657 MPa to 0.827 MPa).

Table 1

Data of soil hardness, moisture content and soil lump adhesion

Depth, mm	**Soil hardness, MPa**			**Soil lump adhesion, MPa**			**Soil moisture, %**		
	Research variant								
	I	II	III	I	II	III	I	II	III
0	0.006	0.227	0.657						
25	0.025	0.397	0.889	0.002	0.017	0.044	4.50	11.30	10.90
50	0.044	0.493	0.827						

In the third variant in the depth of seed insertion the soil lump adhesion was about 22 times greater than in the first variant and about 2.5 times greater than in the second. The soil moisture content was similar in the second and third variants, in the first variant it was about 2.5 times less.

The research has shown that pulling of the hob sowing coulter in the soil loosened by a vertical rotor, the hardness of which is 0.044 MPa, the horizontal traction force was on average about 0.60 kN (Fig. 2), the vertical force was about 0.45 kN and the lateral force was about 0.07 kN.

The research has shown that the horizontal traction force was on average about 0.60 kN (Fig. 3), the vertical force was about 0.26 kN and the lateral force was about 0.02 kN, when pulling the hob sowing coulter in the soil compressed two times by the plain roller of 1000 kg mass, the soil hardness was 0.493 MPa.

The compared operating results of the hob sowing coulter in the soil of 0.044 MPa and 0.493 MPa hardness have shown that the horizontal traction force in both variants was the same (0.60 kN) and in the soil of 0.044 MPa hardness, the vertical traction force was greater by 58 %, and the lateral force by 71 % less.

The research has shown that the horizontal traction force was on average about 0.70 kN (Fig. 4), the vertical force was about 0.20 kN and the lateral force was about 0.14 kN, when pulling hob sowing coulter in the soil compressed six times by the plain roller of 1000 kg mass, the soil hardness was 0.827 MPa.

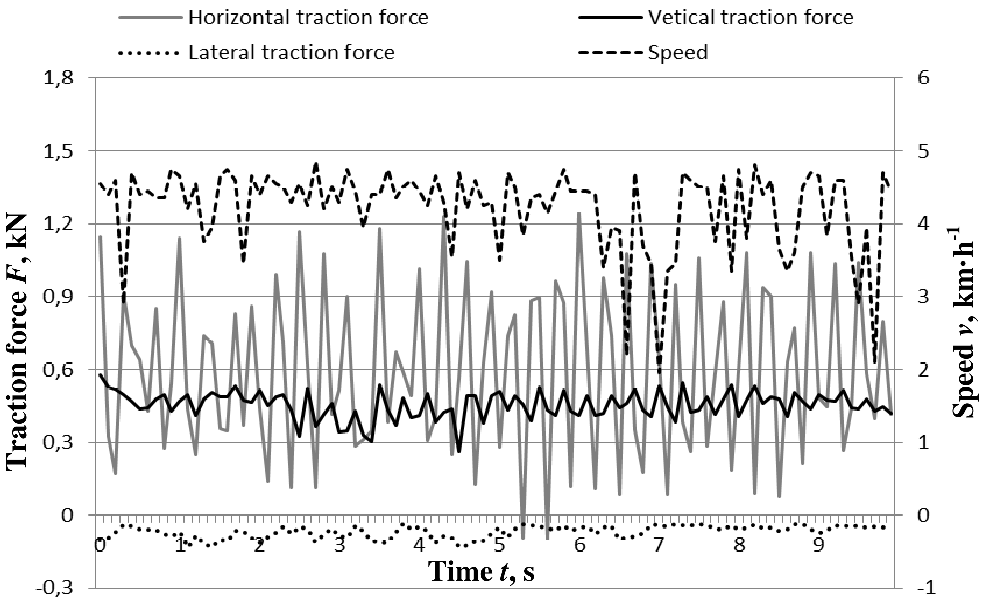

Fig. 2. **Traction forces of hob coulter in the soil of 0.044 MPa hardness**

The horizontal traction force of the hob sowing coulter was by 14 % greater in the soil of 0.827 MPa hardness than in the soil of 0.044 MPa and 0.493 MPa hardness, the vertical traction force was by 56 % less than in the soil of 0.044 MPa hardness and by 23 % greater than in the soil of 0.493 MPa hardness. The lateral traction force was by 75 % greater in the soil of 0.827 MPa hardness than in the soil of 0.044 MPa hardness and by 56 % greater than in the soil of 0.493 MPa hardness.

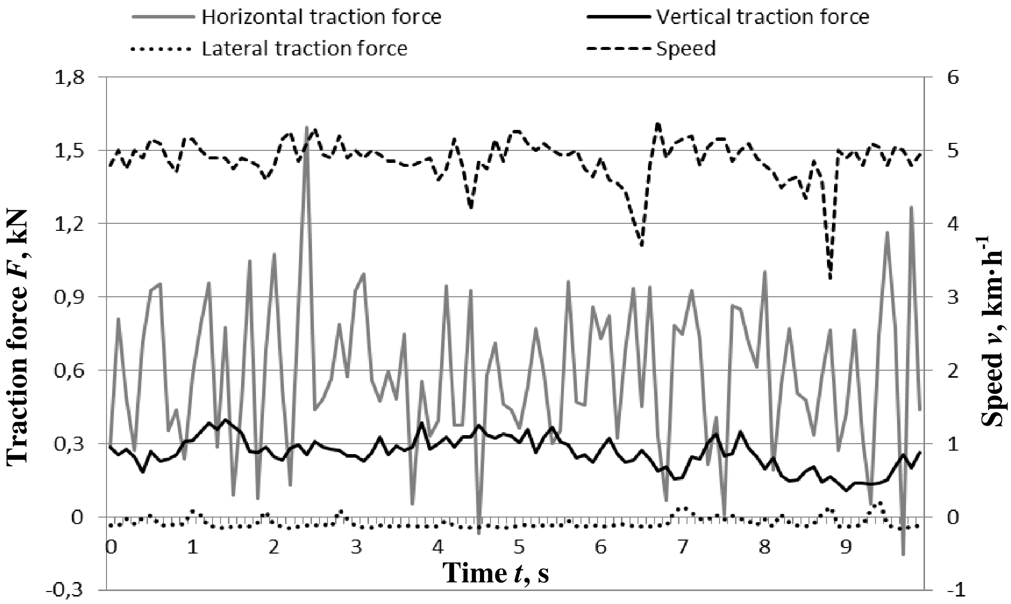

Fig. 3. **Traction forces of hob coulter in the soil of 0.493 MPa hardness**

The research has shown that the horizontal traction force was on average about 0.64 kN (Fig. 5), the vertical force was about 0.49 kN, the lateral force was about 0.02 kN, when pulling the complex sowing coulter in the soil loosened by the vertical rotors, the soil hardness was 0.044 MPa.

The research has shown that the horizontal traction force was on average about 0.63 kN (Fig. 6), the vertical force was about 0.25 kN, the lateral force was about 0.02 kN, when pulling the complex sowing coulter in the soil compressed two times by the plain roller of 1000 kg mass, the soil hardness was 0.493 MPa.

The compared operating results of complex sowing coulter in the soil of 0.044 MPa and 0.493 MPa hardness have shown that the horizontal traction force was similar (in the soil of 0.044 MPa hardness it was 0.64 kN, in the soil of 0.493 MPa hardness it was 0.63 kN), the vertical traction force decreased from 0.49 kN to 0.25 kN, the lateral force decreased from 0.02 kN to 0,02 kN when the soil hardness was 0.044 MPa.

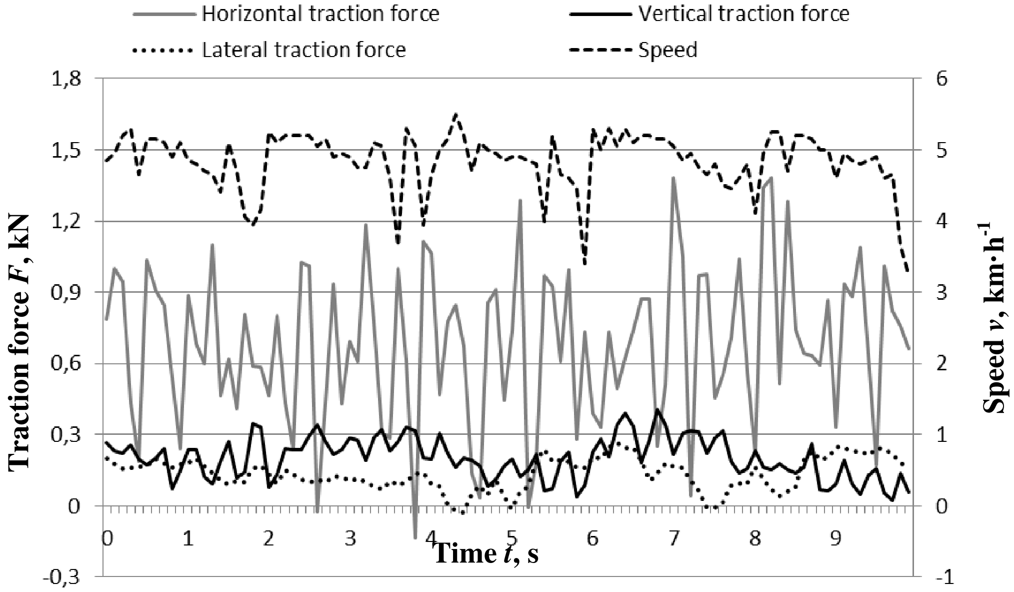

Fig. 4. **Traction forces of hob coulter in the soil of 0827 MPa hardness**

The research has shown that the horizontal traction force was on average about 0.60 kN (Fig. 7), the vertical force was about 0.47 kN, the lateral force was about 0.05 kN, when pulling the complex sowing coulter in the soil compressed six times by the plain roller of 1000 kg mass, the soil hardness was 0.827 MPa.

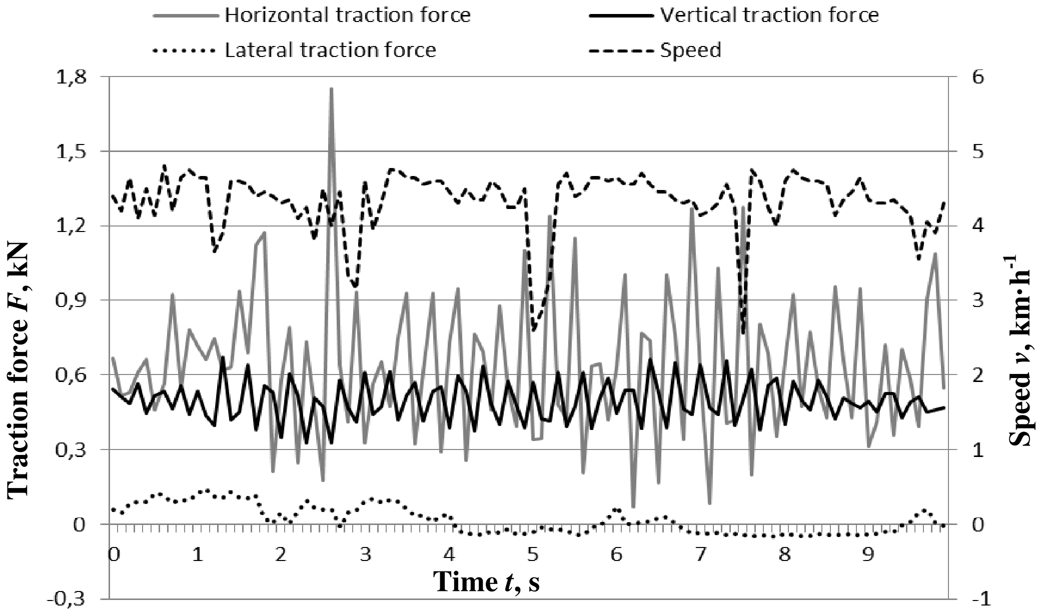

Fig. 5. **Traction forces of complex coulter in the soil of 0.044 MPa hardness**

The horizontal traction force of the complex sowing coulter was about 6 % less in the soil of 0.827 MPa hardness than in the soil of 0.044 MPa and 0.493 MPa hardness, the vertical traction force was by 4 % less than in the soil of 0.044 MPa hardness and by 46 % greater than in the soil of 0.493 MPa hardness. The lateral traction force was by 60 % greater in the soil of 0.827 MPa hardness than in the soil of 0.044 MPa hardness and by 70 % greater than in the soil of 0.493 MPa hardness.

The research has shown that to pull the complex sowing coulter in the soil of 0.044 MPa hardness the horizontal traction force needed is about 6 % greater than for the hob sowing coulters, by 5 % greater force is needed in the soil of 0.493 MPa hardness and by 14 % less force is needed in the soil of 0.827 MPa hardness. When pulling the complex sowing coulter while the soil hardness increased from 0.044 MPa to 0.827 MPa the horizontal traction force decreased, and the horizontal traction force increased when the hob sowing coulter was used.

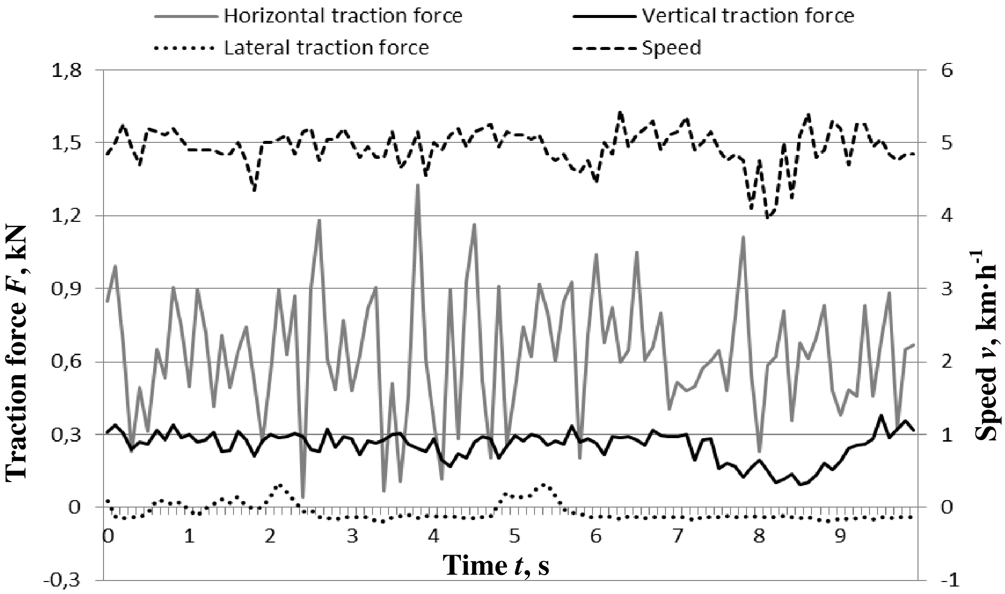

Fig. 6. **Traction forces of complex coulter in the soil of 0.493 MPa hardness**

Moreover, the comparison of the research results has shown that to pull the complex sowing coulter the vertical traction force needed is by 8 % greater than when the hob sowing coulter is used, in the soil of 0.044 MPa hardness, by 1 % less force in the soil of 0.493 MPa hardness and by 57 % greater in the soil of 0.827 MPa hardness. The lateral traction force needed to pull the complex sowing coulter is about 56 % greater than when the hob sowing coulter is used, in the soil of 0.044 MPa hardness, the traction force is the same in the soil of 0.493 MPa hardness, and by 64 % less in the soil of 0.827 MPa hardness.

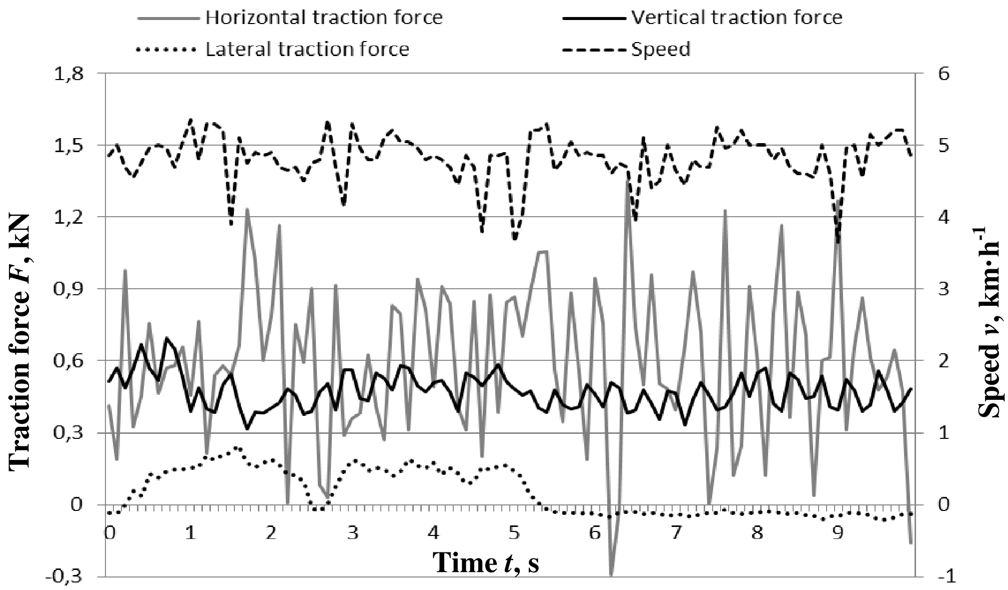

Fig. 7. **Traction forces of complex coulter in the soil of 0.827 MPa hardness**

Conclusions

1. The soil hardness was 0.044 MPa in the depth of 50 mm, soil lump adhesion was 0.002 MPa, moisture content was 4.5 %, in the soil loosened by the vertical rotary cultivator. The soil hardness was 0.493 MPa, soil lump adhesion was 0.017 MPa, moisture content was 11.3 %, in the soil compressed two times by the plain roller of 1000 kg mass and the soil hardness was 0.827 MPa, soil lump adhesion was 0.044 MPa, moisture content was 10.9 %, in the soil compressed six times by the plain roller of 1000 kg mass.

2. To pull the complex sowing coulter the horizontal traction force is needed by 6 % greater than when the hob sowing coulter is used (for the complex sowing coulter 0.64 kN, for the hob sowing coulter 0.60 kN) when the soil is loosened by the vertical rotor and the soil hardness is 0.044 MPa, by 5 % greater force is needed (for the complex sowing coulter 0.63 kN, for the hob sowing coulter 0.60 kN) when the soil is compressed two times and the soil hardness is 0.493 MPa, by 14 % less force is needed (for the complex sowing coulter 0.60 kN, for the hob sowing coulter 0.70 kN) when the soil is compressed six times and the soil hardness is 0.827 MPa.
3. To pull the complex sowing coulter the vertical traction force is needed by 6 % greater than when the hob sowing coulter is used (for the complex sowing coulter 0.49 kN, for the hob sowing coulter 0.45 kN) when the soil is loosened by the vertical rotor and the soil hardness is 0.044 MPa, 1 % less force is needed (for the complex sowing coulter 0.25 kN, for the hob sowing coulter 0.26 kN) when the soil is compressed two times and the soil hardness is 0.493 MPa, by 57 % greater force is needed (for the complex sowing coulter 0.47 kN, for the hob sowing coulter 0.20 kN) when the soil is compressed six times and the soil hardness is 0827 MPa.
4. To pull the complex sowing coulter the lateral traction force is needed by 56 % greater than when the hob sowing coulter is used (for the complex sowing coulter 0.02 kN, for the hob sowing coulter -0.07 kN) when the soil is loosened by the vertical rotor and the soil hardness is 0.044 MPa, the lateral traction force in both variants is the same (-0.02 kN), when the soil is compressed two times and the soil hardness is 0.493 MPa, by 64 % less force is needed (for the complex sowing coulter 0.05 kN, for the hob sowing coulter 0.14 kN) when the soil is compressed six times and the soil hardness is 0.827 MPa.
5. The change of the speed and forces of the complex sowing coulter are less than that of the hob coulter, therefore the complex sowing coulter worked more stable and made the furrow of constant depth.

Acknowledgement

This research was funded by a grant (No. MIP-116/2012) from the Research Council of Lithuania.

References

1. Бондаренко П. А. Агробиологическая оценка посевых машин (Agrobiological evaluation of the seed drill). Механизация и электрификация сельского хозяйства, No. 3, 2005, c. 5-6. (In Russian).
2. Лаврухин П. В. Совершенствование процесса подпочвенного розбросного распределения семян (Improving the process of subsurface seed distribution): диссертация на соискание ученой степени кандидата технических наук. Зерноград, 2000. (In Russian).
3. Šarauskis E., Köller K., Butkus V. Research on technological parameters to determine the design factors of direct drilling coulters for sugar beets. Landbauforschung Volkenrode, vol. 55(3), 2005, pp.171-180. (In German).
4. Sakalauskas A., Šarauskis E., Romaneckas K., Jasinskas A., Vaiciukevičius E. Trials of sugar beet seed pressing with different type pressure rollers. Agronomy research, vol. 5(2), 2007, pp. 135-144.
5. Mishin P., Maksimov E., Drandrov I. Ways of efficiency operation soil–cultivating aggregates. XI International Symposium “Ecological aspects of mechanization of plant production”, 2005, Warszawa.
6. Синеоков Г., Панов И. Теория и расчет почвообрабатывающих машин (Theory and design of tillage machines). Москва, 1987. 328 c. (In Russian).
7. Gebresenbet G., Jonsson H. Performances of seed drill coulters in relation to speed depth and rake angels. Journal of Agricultural Engineering Research, vol. 52(2), 1998, pp. 121-145.
8. Wang J., Gee-Clough D. Deformation and failure in wet clay soil: Part 2, soil bin experiments. Journal of Agricultural Engineering Research, vol. 54(1), 1998, pp. 57-66.
9. Germanas L. Dirvos purenimo sėjos noragėliais rodikliai (Tillage sowing coulters indicators). Žemės ūkio inžinerija: LŽŪII ir LŽŪU mokslo darbai, nr. 37(2), 2005, pp. 14-26. (In Lithuanian).

10. Огрызков Е.П. и др. Оценка сопротивления почв по их твердости (Evaluation of the resistance of soil hardness). Тракторы и сельскохозяйственные машины, No. 3, 2004, с. 24-25. (In Russian).
11. Germanas L. Šiaudų poveikis diskinių sėjos noragėlių pasipriešinimo jėgai (Straw effect of disc sowing coulter resistance force). Žemės ūkio inžinerija: LŽŪII ir LŽŪU mokslo darbai, nr. 38(1), 2006, p. 29-39. (In Lithuanian).
12. Povilaitis V., Germanas L. Juostinės sėjos noragėlio traukos pasipriešinimo jėgų tyrimai (Strip sowing coulter traction resistance forces research). Žemės ūkio inžinerija: LŽŪII ir LŽŪU mokslo darbai, vol. 39 (2), 2007, p. 26-37. (In Lithuanian).
13. Šarauskis E. Cukrinių runkelių sėjos ražienoje sudėtinių noragėlių technologinių parametrų pagrindimas (Substantiation of technological parameters of complex coulters in sugar beet mulch seeding): Dissertation of technological sciences. Lithuanian University of Agriculture, 2001, p. 98. (In Lithuanian).
14. Ranta O., Koller K., Ros V. etc. Study regarding the forces that occurs in a no-till technology process in relation with geometrical parameters of the coulter discs. Bulletin UASVM, Agriculture, vol. 65 (1), 2008, pp. 223-228.
15. Celik A., Raper R.L. Design and evaluation of grouvn-driver rotory subsoilers. Soil & Tillage Research, vol. 124, 2012, pp. 203-210.