DETERMINATION OF SUBSOILER TRACTION FORCE INFLUENCED BY DIFFERENT WORKING DEPTH AND VELOCITY

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Abstract. The paper presents experimental researches conducted in the field using a soil loosening equipment with 5 working active bodies (subsoiler), simultaneously with an equipment for breaking up the clods risen to the surface and the soil crust, resulted from passing of the subsoiler active bodies through the soil, at working depths of: 20 / 30 / 40 / 50 cm, respectively, with 5 different working speeds. By modifying the depth for each working speed, the specific fuel consumption and traction force necessary for performing the loosening operation were determined, taking into consideration the soil humidity and hardness.

Keywords: subsoiler, soil, depth, working speed.

Introduction

Since the climate change scenarios predict, in most semi-arid regions of the world, an increase in temperature, changes in precipitation patterns and longer periods of drought, which lead to soil degradation, in Europe researches are carried out on soil respiration, which is one of the main processes responsible for the loss of organic matter. The studies carried out have shown that soil degradation could alter the carbon balance of these ecosystems through changes in temporal dynamics of soil respiration and plant productivity, which have important negative consequences for the functioning of ecosystems in time [1].

In Romania, the main process of soil degradation is erosion by water, which along with landslides affects over 7 million ha of agricultural soil. The second important factor in soil degradation is the periodic moisture excess, which affects 3.8 million ha of agricultural soil, while frequent droughts excess manifests on approx. 7.1 million ha of agricultural soil. In this context, through the work presented, a new approach of soil works is proposed in the arable substrate specific to heavy and compacted soils, affected alternatively by excess and deficiency of moisture and also for other types of soils, which show limitations of production capacity because of salinization, alkalinization, pollution etc.

The studies on the mechanization technology for deep decompaction and aeration of defective soil, aspects concerning the soil penetration resistance after deep soil loosening work and energetic consumption of the deep soil loosening work [2-4] highlighted the need for deep loosening works at least once every 4 years. In order to reduce the resistance during operation and the fuel consumption, researches were developed for unifying the resistance expression of machines designed to soil tillage with applications in their working regime optimization, and also structural analysis of the resistance structure as a component of equipment with active working parts driven to deeply loosen the soil was performed [5-7].

Materials and methods

Experimental researches in the field were made on agricultural soil on which wheat was harvested at CRINA Bărcăneşti agricultural society, in Olt County (Romania), in order to determine the qualitative and energy indices, using a CASE INTERNATIONAL 7140 tractor in aggregate with the equipment for soil decompaction (SCAR 5).

Considering that the soils in this area have a structure, which recommends them as medium-heavy soils, and the equipment has 5 bodies (over 2 m – working width), the recommended energy source should be about 200 HP, in this case being a tractor of 143.5 kW (195 HP) used.

The equipment for decompaction of deficient soils (Fig. 1), which has been used in the experimental research, consists of the following main assemblies:

- chassis to ensure coupling of the equipment in three points to the rods of the tractor hydraulic lifter, catching of the 5 active bodies for deep loosening of soil in the arable substrate and the support of nutrient application equipment;

- active bodies with reversible chisel knives and special knives for hardpan removal;
- claw rollers placed behind the active bodies for shredding and easy levelling of the processed soil;
- left / right support wheels to provide adjustment and limitation of the working depth of the active bodies.

Fig. 1. **Technical equipment for decompaction of deficient soils**

The main technical characteristics of the equipment used in the experiment are:

- number of loosening bodies: 5;
- number of shredding bodies: 2;
- maximum working depth: 0.6 m;
- working width: 2.3 m.

Components of the technical equipment for decompaction of deficient soils related to the adjustment system of transport height and the elastic system for soil copying for roller batteries are made in accordance with [8] and [9]. To determine the qualitative and energy indices in the field the following devices of measuring, control and data acquisition were also used:

- mechanical timer;
- apparatus for determining the fuel consumption;
- HH2 moisture meter produced by Delta-T Devices;
- electronic balance;
- device for measuring the wheel speed;
- resistive strain transducers (strain gauges);
- digital measuring system with data acquisition MGCplus [6];
- software for data processing GlyphWorks-nCode ICE-flow [7].

Fig. 2. **Strain gauges glued on the tractor rods**

In order to determine the qualitative work indices, strain gauges were glued on the lateral and central rods (surfaces have been cleaned and polished before gluing), Fig. 2, then the apparatus for determining the fuel consumption (flowtronic type) was mounted on the tractor, strain gauges and the system were calibrated, and the soil was divided in plots of 50 m length.

Determination of the tensile strength was performed using resistive strain gauge transducers mounted on the three-point linkage of the tractor unit, and the data acquisition was performed using a laptop and a digital measuring system with data acquisition type MGCplus, equipped with Cadman special software for acquisition, processing and filtering of raw data. The system was fed with power from the tractor battery using a voltage inverter. The GlyphWorks-nCode ICE-flow software enabled faster data processing and graphical drawing of their minimum, average and maximum values.

Experimental research in the field (operation) is aimed to determine the following indices of qualitative work:

- Degree of soil compaction;
- Loosening degree;
- Average working depth;
- Average working width.

For each determination, the measurements were performed 5 times, in the following tables and graphics their average value being given.

The traction power P_{tr}, kW was calculated on the basis of the aggregate displacement speed v_l (3.6×m·s^{-1}) or (km·h^{-1}) and traction force F_{tr} (N) previously determined by means of relation [10; 11]:

$$P_{tr} = \frac{F_{tr} \times v_l}{3600}. \qquad (1)$$

The following indices of qualitative work were determined with the technical equipment in the aggregate with 143.5 kW (195 HP) tractor.

The degree of soil compaction was calculated according to the following equation:

$$G_T = \frac{PO_{\min} - PO_e}{PO_{\min}} \cdot 100\,\%, \qquad (2)$$

where $PO_{\min}$ – minimum porosity required to a soil suitable for crops, %;
PO_e – effective porosity of the soil, %.

Porosity was calculated according to the following equation:

$$PO = 100(D - \frac{DA}{D}) = 52.38\,\%, \qquad (3)$$

where DA – apparent density 1.32 g·cm^{-3};
D – specific density 2.52 g·cm^{-3}.

From the above equation it results that the degree of soil compaction, which determines the need for loosening works, is a characteristic of the physical condition of the soil at any given time. The porosity of a top soil was determined with A mollic horizon (Am) with chromes ≤ 2 (dark colours, blackish, dark brown), clay content of 57.8% (under 0.01 mm %), in the area of CRINA Bărcăneşti agricultural society in Olt County.

Table 1 presents the determined values of the degree of soil compaction in horizon Am.

Table 1

Degree of soil compaction

Indices	**Depth, cm**		***PO***		
Values	Horizon Am	0...24	60	48	20.00
		24...42	54	44	18.52
		42...57	52	43	17.31

Loosening degree was calculated according to the following equation:

$$G_{as} = \frac{\sum_{i=1}^{n} \frac{h_1 - h_2}{h_1}}{n} \times 100\,\%, \qquad (4)$$

where h_1 – ordinate at a certain point on the ruler at the soil surface before passage of the equipment, cm;
h_2 – ordinate at the same point on the ruler at the soil surface after passage of the equipment, cm;
n – number of measurements.

Table 2 presents the determined values of the degree of soil loosening.

Table 2

Degree of soil loosening

Indices		h_1, cm	h_2, cm	G_{as}, %
Repetition	1	181	151	18.26
	2	204	167	
	3	198	161	
	4	189	157	
	5	194	154	

Average working depth was determined by measuring the distance between the soil surface and the bottom of the furrow left by the active body and was calculated according to the following equation (result in cm):

$$a_m = \frac{\sum_{i=1}^{n} a_i}{n}, \tag{5}$$

where a_i – the measured working depth, cm;
n – number of measurements.

The variation index of the working depth was calculated according to the following equation:

$$V_a = \frac{\sigma_a}{a_m} \times 100\,\% \cdot \tag{6}$$

Table 3 presents the determined values of average working depths.

Table 3

Average working depth

Indices		a_i, cm	a_m, cm	V_a, %
Repetition	1	58.2	60.16	1.24
	2	61.4		
	3	59.2		
	4	60.8		
	5	61.2		

Average working width was calculated according to the following equation (result in m):

$$B_m = \frac{\sum_{i=1}^{n} B_i}{n},$$

where B_i is the measured working width, m;
n – number of measurements.

The variation index of the working width was calculated according to the following equation:

$$V_B = \frac{\sigma_B}{B_m} \times 100\,\% \cdot \tag{8}$$

Table 4 presents the determined values of the average working width.

Table 4

Average working width

Indices		B_i, cm	B_m, cm	V_B, cm
Repetition	1	232	231.2	4.14
	2	234		
	3	228		
	4	226		
	5	236		

After processing the experimental data for stabilized working regimes, according to times performed in completing the work space s (s), the average values of the working speed v ($m \cdot s^{-1}$) and traction forces F_t (N) for different working depths a ($a_1 = 0.20$ m; $a_2 = 0.30$ m, $a_3 = 0.40$ cm, $a_4 = 0.50$ m) were determined.

Results and discussion

The results obtained were compared to the results obtained in idle time ($a_0 = 0$ m), when covering the same working space with the aggregate ($S = 50$ m). Average values of these data are shown in Table 5.

Table 5

Parameters measured during work for different velocity steps of the aggregate

Tractor velocity step	Parameters measured during operation	Working depth a, cm				
		$a_0 = 0$	$a_1 = 0.20$	$a_2 = 0.30$	$a_3 = 0.40$	$a_4 = 0.50$
1	Time t_1, s	50	51	54	56	75
	Working speed v_1, $m \cdot s^{-1}$	1	0.9804	0.9259	0.8929	0.6667
	Traction force F_{t1}, N	9639	12730	24170	34880	51840
2	Time t_2, s	40	42	45	50	65
	Working speed v_2, $m \cdot s^{-1}$	1.25	1.1905	1.1111	1	0.7692
	Traction force F_{t2}, N	9639	17180	25450	38190	54350
3	Time t_3, s	39	42	44	46	52
	Working speed v_3, $m \cdot s^{-1}$	1.2821	1.1905	1.1364	1.0870	0.9615
	Traction force F_{t3}, N	9639	19010	27930	40410	54440
4	Time t_4, s	35	37	44	46	47
	Working speed v_4, $m \cdot s^{-1}$	1.4286	1.3514	1.1364	1.0870	1.0638
	Traction force F_{t4} (N)	9639	21160	30930	41030	54055
5	Time t_5, s	28	29	30	31	45
	Working speed v_5, $m \cdot s^{-1}$	1.7857	1.7241	1.6667	1.6129	1.1111
	Traction force F_{t5}, N	9639	24070	33980	42200	54920

The soil moisture measured in the plot in which the assays have been performed (Fig. 3). ranged between: 24÷28 % (out of volume) and the penetration resistance (Fig. 3) had a maximum value of 980 kPa (15 cm); 1286 kPa (30 cm) and 1684 kPa (45 cm), which are very high values for both moisture and penetration resistance due to the fact that it rained about a week before, but mostly because the soil in that plot has not been subsoiled for over 20 years.

Fig. 3. **Measurement of soil moisture and penetration resistance**

To determine the traction force (Fig. 4) in operation, the MGCplus acquisition system was used, the decompaction equipment being set to the maximum working depth of 60 cm. The variation of the traction force measured at the rods of the tractor, at the adjusted working depth of 60 cm, is shown in Figures 5 and 6.

Fig. 4. **Aspects from the experiments with the decompaction equipment**

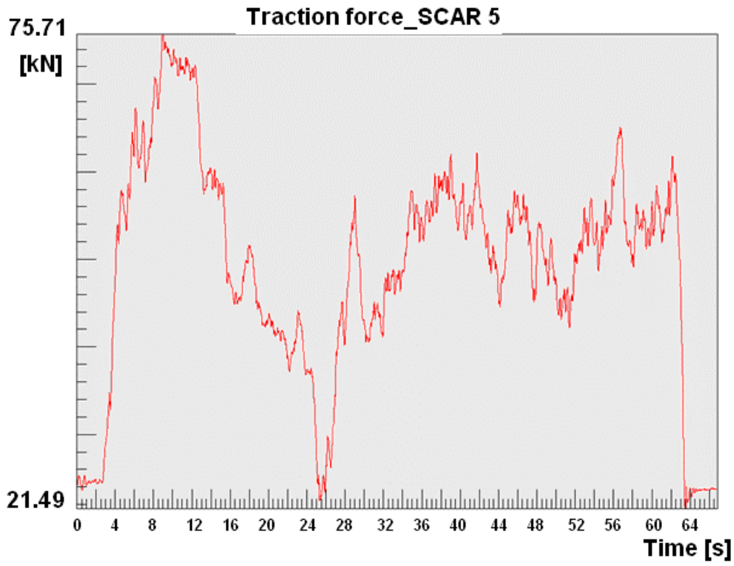


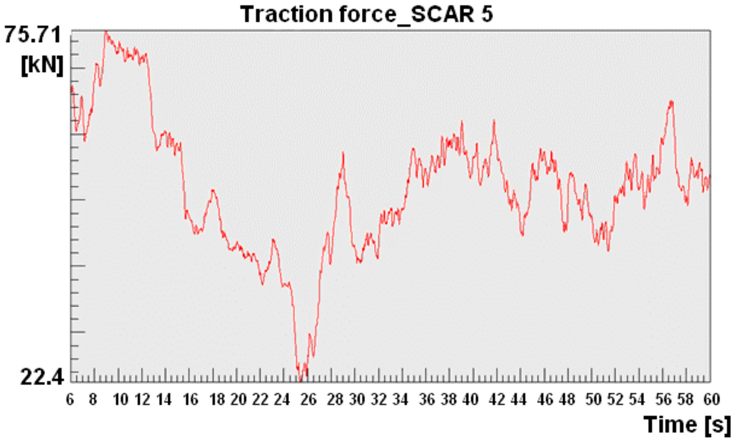
Fig. 5. **Variation of the traction force at working depth of 60 cm**

Table 6

Values of penetration resistance, R_p (kPa)

Den. No.	**Working depth, *a* m**	**Soil humidity *U* (%) at average depth of 0.22 m**				
		24.1	24.8	26.2	27.1	28.2
		Penetration resistance, R_p (kPa)				
1	0.025	807	105	140	526	70
2	0.050	737	772	1018	596	386
3	0.075	596	983	877	877	912
4	0.100	561	948	807	1053	877
5	0.125	596	807	983	1053	877
6	0.150	807	807	1088	983	877
7	0.175	807	1299	1509	1580	807
8	0.200	912	1228	1228	1615	772
9	0.225	1369	1123	1369	1369	772
10	0.250	1544	1158	1299	1369	702
11	0.275	1615	1088	1158	1299	948
12	0.300	1650	1158	1193	1404	1088
13	0.325	1790	1193	1193	1369	1158
14	0.350	2071	1193	1334	1299	1123
15	0.375	2141	1334	1474	1334	1228
16	0.400	2141	1544	1615	1369	1228
17	0.425	2247	1790	1720	1369	1228
18	0.450	2247	2001	1650	1439	1123

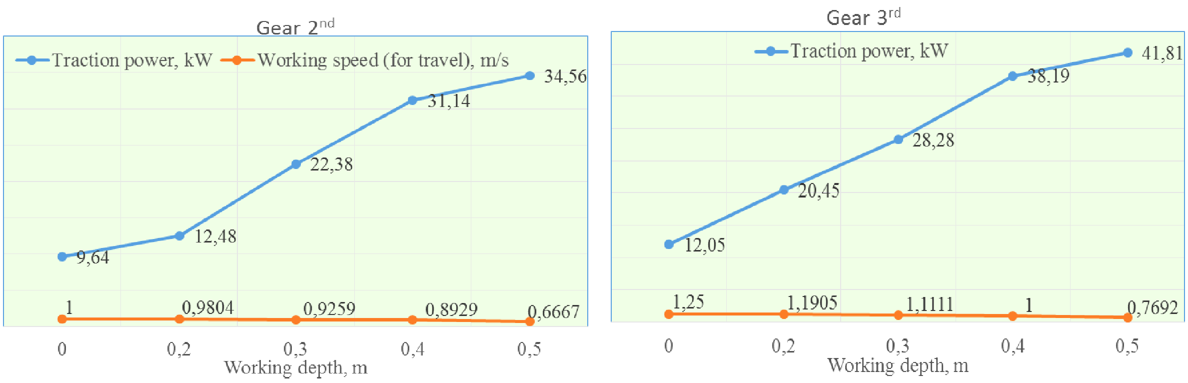
From the data processing program using GlyphWorks-nCode ICE-flow program it resulted that the minimum value of the tensile strength is ($F_{tr\ min}$ = 22.4 kN), average ($F_{tr\ med}$ = 51.84 kN) and maximum ($F_{tr\ max}$ = 75.71 kN) for the working depth of 60 cm (Fig. 6).



Y Max	75.71
Y Min	22.40
Y Mean	51.84

Fig. 6. **Minimum, average and maximum traction force at working depth of 60 cm**

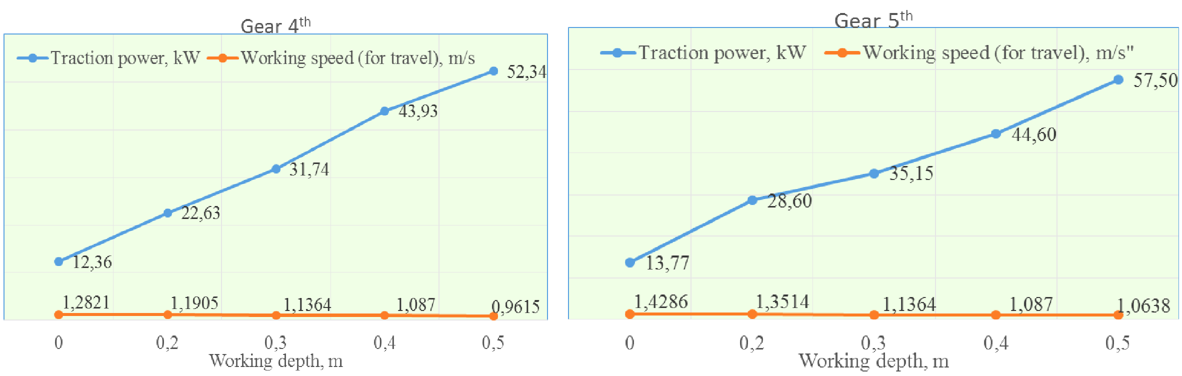
For the 3 speeds of the decompaction equipment for deficient soils working in the aggregate with the tractor, the variation of energy indices was determined (Fig. 7).



For 2-nd velocity step and For 3-rd velocity step

Fig. 7. **Traction force and working speed depending on the working depth**

In Figures 7, 8 and 9 the variations of the traction force and working speed of the tractor + technical equipment aggregate depending on the working depth *a* (m), for the 2-nd, 3-rd, 4-th, 5-th and 6-th velocity step of the agricultural tractor CaseIH 7140 are shown as a graphic.



For the 4-th velocity step and For the 5-th velocity step

Fig. 8. **Traction force and working speed depending on the working depth**

The specific fuel consumption found for soil loosening at depths of 20 / 30 / 40 and 50 cm with the SCAR 5 equipment is shown in Figure 10.

Fig. 9. **Traction force and working speed depending on the working depth (in the 6-th velocity step)**

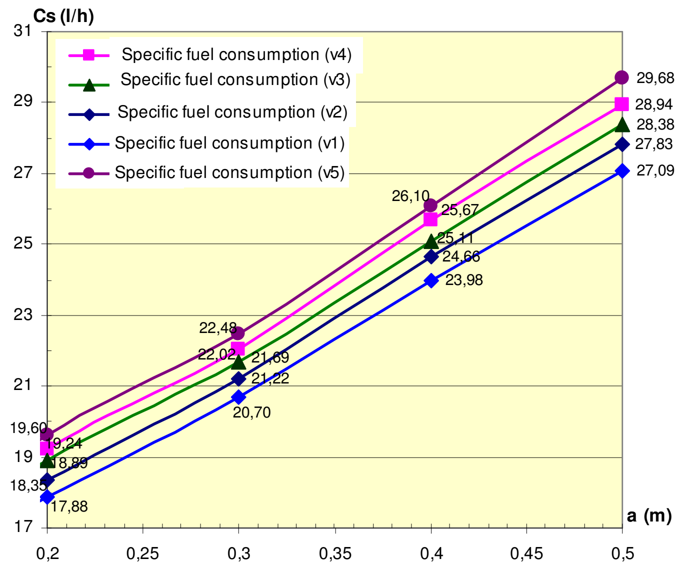


Fig. 10. **Specific fuel consumption depending on the working depth**

After the experimental research carried out using the technical equipment for decompaction and deep loosening of deficient soils, it resulted that:

- In functional terms, the technical equipment has accomplished the qualitative indices, which are in accordance with the agro technical requirements for the works of improving the conditions of aeration and soil permeability;
- In terms of energy, the technical equipment has achieved appropriate energy indicators, in the aggregate with the CASE INTERNATIONAL 7140 tractor, with good stability during operation.

The experimental results have allowed the development of useful recommendations for farmers, who apply the technology of soil loosening without turning, reversing or mixing soil horizons.

Conclusions

As a result of the experimental researches performed by the equipment for soil deep loosening (SCAR 5), the following conclusions have been drawn:

- soil loosening mostly depends on the soil type: argillaceous, clayey, or clayey-argillaceous, the operation being more difficult to perform in argillaceous soils, respectively the soil in which the experiments were done;
- soil humidity (higher or lower than the optimum humidity) negatively influences the process of soil loosening as well as the power necessary to perform the operation (because of high skidding); increased humidity leads to higher fuel consumption;

- the soil compaction degree negatively influences the loosening process, in case of soils in which loosening was not performed for more than 5 years (such, in which the researches were performed), the necessary power and the fuel consumption increase;
- the traction force and fuel consumption are increasing with the velocity and the working depth, at bigger depth great traction forces and greater power are necessary.

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