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Trials of sugar beet seed pressing with various pressure rollers

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Abstract. This paper presents the investigation of the technological process of operation of special type sugar beet seed pressure rollers and the experimental trial results of tests carried out in various soils at Hohenheim University. Pressure rollers are mounted behind the seeder coulters, improving the contact between sugar beet seeds and the soil and, in addition, improving seed germination ability. But pressure rollers of conventional sugar beet seeders used for sowing tilled and cultivated soils cannot always be used for seed pressing in non-ploughed and uncultivated soils. The main design parameters of the pressure rollers of sugar beet seeds are diameter, width, the number of rollers and fingers, mass, etc. The even pressing of seed, furrow bed profile, its hardness, seed damage and gravity, etc. depend on the above mentioned parameters.

The theoretical investigations proved that the pressure rollers should be mounted on the seeder unit with the help of hinges. As a result, when the sugar beet seeds were sown in non-ploughed soils, the pressure force onto the soil would depend on the gravitational force The diameter of the pressure rollers should be not less than 180 mm in order to press the seeds into the soil to a depth of about 3 mm and ensure their good contact with the soil.

The experimental trials revealed that the narrow disk pressure roller of 220 mm diameter and 15 mm width introduces the seeds of sugar beet into the hard soil of 0.4 and 0.9 MPa and satisfies the conditions of good seed and soil contact. The disk pressure roller with fingers is made of two disks; each 17-finger disk introduces sugar beet seeds by 2 mm shallower than the narrow one and forms waves in the furrow bottom. When the finger-type pressure roller has been pulled through 0.4 – 0.9 MPa hardness soil the recommended force should be from 0.004 to 0.011 kN greater than using the narrow pressure roller.

Key words: design of pressure roller, sugar beet, furrow bottom, soil hardness, gravitational force

INTRODUCTION

In Western European countries the seeds of sugar beet are sown into minimally or completely uncultivated soil. These soil cultivation and sowing technologies reduce the expenditures for the production of agricultural crops. In addition, the soil structure of uncultivated soil improves and its biological activity increases. The small number of runs through the technological tracks exerts minimal pressure on the soil.

The introduction of the sugar beet seeds into the stubble are much more complicated if compared with conventional sowing into properly prepared soil. It is difficult to make clean furrows at even depths in the hard soil surface full of yield waste materials and, therefore, not easy to create good germination conditions for the sugar beet seeds (Šarauskis et al., 2005).

The design of pressure rollers and support wheels, and the method of their fastening to the sugar beet drill section have some influence on the technological process of sowing and the quality of the seed introduction. When the pressure roller has been rigidly fastened to the drill section it presses the seeds into the soil and at the same time fulfills the function of support wheel and maintians the constant depth of the coulter dive. The gravitational force of the whole section acts on both pressure roller and support wheel. In addition, the pressure roller and the support wheel have their own gravitational force. When the sugar beet seeds are sown into the stubble, which has a top soil surface several times harder than conventionally cultivated soil, the seed introduction is rather complicated. Thus the grain drill sections must be of sufficient weight in order to introduce the sugar beet seeds into the proper depth. For the same reason the pressure roller and the support wheel are more heavily weighted.

When the pressure roller is wider than the furrow width on the soil surface, the soil is pressed rather widely; the sugar beet seeds are not introduced into the furrow bottom made with the coulter, and there is no good contact between seeds and soil. Furthermore, the pressure roller compresses the top layer of the soil above the implanted seeds and hinders germination because the sprouts cannot reach the soil surface. When the pressure roller is narrower than the furrow bottom width then only the narrow area of the furrow bottom is pressed. In this case the pressure roller moving through the pressed furrow bottom may damage the seeds because the gravitational force acts on the small area of the roller.

The pressure rollers press the soil, change its plastic and elastic characteristics and thickness, depending on soil granulometric composition, structure, moisture, hardness, humus amount, cultivation depth, etc. (Uppenkamp, 1986). Soil density has some influence on the temperature and the moisture variation in the soil.

The density of the furrow bottom has an impact on the germination ability of sugar beet seeds, yield and sugar content. The most beneficial position for the introduced seeds is to be laid on the thicker bottom of the furrow, with the more porous soil layer on the top. German scientists (Spicher et al., 1986; Steide et al., 1989) have determined that the best seed germination was evident when the density of the furrow bottom is from 1.27 to 1.37 g cm^{-3}. They state that when the seeds are laid on the denser furrow bottom (from 1.4 to 1.7 g cm^{-3}), the yield decreases by 1 ton per ha, and the sugar content is minimized by 20%. According to the data of the Rumokai experimental station, the sugar beet seeds germinated most effectively when the furrows were made in the soil density of 1.25 g cm^{-3}. Scientists assert that the soil density above the seeds should be 0.8–0.9 g cm^{-3} (Naudžiūnas, 1986; Rademacher, 1988).

The trials fulfilled at Hale University showed that the design of the pressure rollers has some influence on the soil density. The pressure rollers should be installed in front of the soil filler, rather than behind it or on both sides of it. When the pressure roller is behind the soil filler the seeds are not touched as the roller runs on the soil surface (Papesch et al., 1998).

Tessier et al., 1991 state that the pressure on moist soil above the seed may be harmful. The greater the soil moisture, the less it should be pressed: narrow rollers should be used in dry soils and wider-pressure rollers in moist soils.

Linke, 1998 states that the roller action on the furrow bottom depends on the coulter design. For better pressure, it is preferable to make furrow bottoms with anchor coulters rather than with disk coulters.

Steiner, 1994 tested pressure rollers of various widths. He determined that when the roller runs through the soil surface, the 30 mm-depth soil was most efficiently pressed when the cylinders and fingers are used; at soil depth of 30 to 60 mm, pressure rollers of V-form are preferable.

Uppenkamp, 1986 tested the impact of pressure rollers of various designs on the soil. He stated that double-disk pressure rollers with the surface slanting formed the hillock of 17mm height above the seed introduction furrow. The slanting of the hillock sides comprised the angle of 28^{o} to the horizontal. The cylinder pressure roller with a rubber surface pressed the soil layer of 10.5 mm depth, the comparable roller with fingers pressed the soil at a depth of 10 mm and made pits of 10 mm depth at 20 mm distances from each other.

Wahode, 1985 tested the soil pressure above the seeds when the double-disk pressure rollers with slanting rubber surfaces (90 mm thickness, 250 mm diameter, 12 kg mass) with fingers (65 mm, 280 mm, 4 kg) were used. Specifically, she stated that cultivated stubble of 17% moisture content was pressed much more effectively when double-disk pressure rollers with surface slanting were used. They compressed the top layer of the soil surface up to 40 mm, while the cylindrical pressure rollers with rubber surface and fingers compressed the soil layer to 25 mm.

Haberland, 1997 stated that sugar beet seeds in the furrow bottom of the stubble should be pressed in moderation because they can be damaged. Rademacher, 1990 proposes pressing coated sugar beet seeds into furrow bottoms at a depth of 2–3 mm.
Various state research institutions of Western Europe conduct trials of sugar beet stubble furrow drill coulters, disk knives, and yield residue removers, however, unfortunately, there are no trails of pressure rollers of sugar beet seeds for sowing into stubble.

The aim of the investigation is to define the impact of the pressure rollers of various types on the hardness of the furrow bottom, profile and gravitational force when sugar beet seeds are introduced into soils with various characteristics.

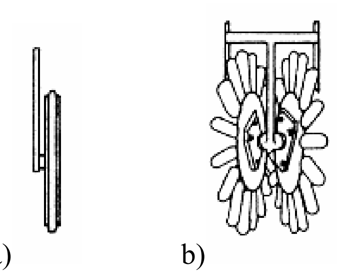
MATERIALS AND METHODS

Trials were carried out in the Agricultural Technical Institute of Hohenheim University, Germany, in the trial premises with the length of 46 m, 5 m width, and the soil layer depth 1.2 m. The soil structure was 72% sand, 16% clay loam and 12% clay. The soil was cultivated with a 1–5 m wide vertical rotor cultivator, and pressed with a 1.3 m width roller of 1000 kg mass. The soil was pressed with rollers in two different variants: the first variant included two replications; the second, six. The soil hardness was measured with a manual penetrometer with a time indicator (the value of one graduation is 6894.7 Pa), the engagement of soil clods was measured using a gauge with a blade-type propeller tip (the value of one graduation is 0.04788 kPa); moisture was measured with volume moisture meter “TRIME-FM”. The measurements were carried out with five replications at the depth of 50 mm.

Sugar beet seeds “Marhaton” were introduced with one drill section with pressure rollers of different types: one disk-type was narrow and one had fingers (Fig.1). The narrow disk-type pressure roller was 220 mm diameter, 15 mm width, and 1.4 kg mass. The disk-type pressure roller with fingers had two 340 mm diameter disks with fingers installed at a 20^{o} angle. Each disc had 17 fingers of truncated cone. All the finger tips had rubber tip coatings.

After sowing, the seed introduction depth was measured with a ruler.

The soil profile formed with pressure rollers was measured with a manual roughness indicator that consisted of the frame with 2 mm diameter tines. The tine number could be changed from 0 to 100. The tines are distributed in one line at distances of 4.5 mm. The tine position was fixed with a bracket hinged with springs. When the fixing unit was released the tines fell down onto the soil surface.



a) b)

Fig. 1. Pressure rollers: a) narrow disk type; b) disk type with fingers.

The hardness of the furrow bottom was measured with a manual penetrometer that consisted of eleven needles of 2 mm diameter, distributed at spaces of 13 mm. The middle needle, joined with sensors, fixed the hardness of the furrow bottom. The depth sensor measured the depth of the tine dive (Šarauskis, 2001).

Resistance to gravity force of the sugar beet sections with various types of pressure rollers was measured with a gravity force meter consisting of a two-part frame with six sensors. One part of the frame was mounted on the self-propelled axle vehicle, another was fixed to the tested section. The measurement limits were from 0 to 10 kN. The pressure rollers were pulled with the speed of 1.39 and 1.94 m s^{-1}.

Data obtained by investigation was evaluated using methods of dispersion and correlation-regression analysis. Arithmetic means, their standard errors, and confidence intervals at probability level of 0.95 were determined.

RESULTS AND DISCUSSION

When sugar beet seeds were sown into uncultivated soil, the drill coulters penetrated the soil surface less than in minimally cultivated soil. To determine the sowing depth, the drills should have greater weight which increases the action of gravitational force on the coulter, and allows it to dive more easily. But in very hard soils (more than 1.0 MPa) the pressure roller may not touch the soil surface when the coulter dives, thus does not fulfil its function. Therefore the study concludes that the pressure rollers should be attached to the sugar beet drill on hinges, but not rigidly. Gravitational force of the pressure rollers should not depend on the section and the whole mass of the drill.

In uncultivated soils the pressure rollers have to introduce seeds into a minimal depth of (2–3 mm) in order to have good contact between the seeds and the soil. When the seeds are pressed deeper they can be damaged (Rademacher, 1990).

The pressure roller presses the seeds into the soil properly when the lumps in the soil are smashed. The following conditions should be fulfilled to achieve this: the lump pressure angle α_0 should be less than the sum of the friction angles (pressure on the lump angle φ_1 and the lump pressure on soil angle φ_2) (Šarauskis et al., 2003):

$$\alpha_0 < \varphi_1 + \varphi_2 .$$

When the angle α_0 is greater than the sum of the friction angles the soil lumps are pushed in front of the roller. The pressure angle is determined by experiments and most often it is 15^o – 20^o (Buckel et al., 1986). When the pressure angle and the pressure depth are known, the pressure roller diameter can be calculated as follows:

$$d \geq \frac{2h}{1 - \cos\alpha_0} ,$$

where: d is pressure roller diameter, mm;
h is pressure depth, mm.

Depending on the soil pressure depth and pressure angle, the diameter of the pressure roller was changed. When the pressure angle is $\alpha_0 = 15^o$, and soil pressure depth is 3 mm, the diameter of the pressure roller should be not less than $d \geq 180$ mm.

A pressure roller with a pneumatic tire can press the soil at the same depth as the roller with a hard surface, but the roller diameter should be increased. It is difficult to install a roller with a wide diameter so that it can press the seeds directly after they are sown from the grain drill sowing apparatus. If there is any gap between the spread seeds and pressure roller, the furrow bottom may be contaminated with lumps of various sizes, straw, etc. Thus it is better to use smaller hard rollers with a rubber surface. The rubber protects seeds from damage.

The dependence of gravitational force F_G on the main parameters of the pressure roller is defined according to the equation (Soucek et al., 1990):

$$F_G = \frac{2bqh\sqrt{dh}}{3} \cdot 10^{-6} ,$$

where: b is the width of the pressure roller, mm;
q is volumetric coefficient of soil pressure, N mm^{-3}. In the cultivated soil it is (1–10)10^3 N mm^{-3}; in uncultivated porous soil, (10–30)10^3 N mm^{-3}; in uncultivated medium hard soil it is (30–50)10^3 N mm^{-3}; in uncultivated hard and extremely hard soil it is more than $50 \cdot 10^3$ N mm^{-3}.

When the diameter of the pressure roller is $d = 200$ mm, the width is $b = 20$ mm, $q = 40 \cdot 10^3$, the soil will be pressed at the depth of 2.5 mm with 30 N gravitational force. When the roller diameter is increased two times, the gravitational force should be 42 N. If the roller width is reduced to 15 mm, when $d = 200$ mm, the gravitational force drops down to 21 N. If the pressure roller width is increased up to 25 mm, the gravitational force increases up to 38 N.

The soil pressure increases when the area of the pressure roller contact with the soil is reduced. The disk-type pressure rollers with fingers touch the soil surface only with the finger tips. The distance between the pressure centres of adjacent fingers of the pressure roller onto the soil is calculated by the following equation:

$$l = \frac{2\pi R}{n_p \cdot n_v},$$

where: l is the distance between the adjacent fingers pressure centres onto the soil, mm;
R is the radius of the disk pressure roller with fingers, mm;
n_p is the number of pressure roller fingers, units;
n_v is the number of disk rollers with fingers, units.

When the number of pressure roller fingers is increased, the distance between the pressure centres of adjacent fingers into the soil decreases. This distance should be such that the sugar beet seeds would all be pressed and should have good contact with the soil. Every finger presses the corresponding soil area. The non-dense soil area between the pressing area of adjacent fingers should be not greater than the thickness of sugar beet seeds, i.e., 3–4 mm. When the radius of finger tips is from 10 to 15 mm, the distance between the pressure centres l of adjacent fingers should be from 23 to 33 mm. When the radius of disk-type pressure roller with fingers is 150 mm, the distance l is provided by 28–38 fingers.

It is not easy to manufacture the disk roller with 28–38 fingers with a tip radius of 10 to 15 mm. The same pressure could be reached with two kinematically connected disk rollers with twice less the number of fingers, but they should be fastened to make the angle so as to ensure that the finger tips of both rollers would run through the soil and press it in one line.

It has been shown in experimental trials that in the 1st variant (twice pressed with the rollers) the soil hardness in the depth of the introduction of sugar beet seeds was the same as that in the uncultivated light clay loam soil (approximately 0.4 MPa) (Table 1). In the 2nd variant (pressed 6 times with the rollers) the soil hardness was two times greater and corresponded to the hardness of the uncultivated medium hard clay loam soil (about 0.9 MPa).

Table 1. Data of soil hardness, moisture and lump engagement.

Depth, mm	Soil hardness, MPa		Soil lump engagement, MPa		Soil moisture, %	
	Experiment variant					
	I	II	I	II	I	II
0	0.227	0.657				
25	0.397	0.889	0.017	0.044	11.3	10.9
50	0.493	0.827				

In the second variant, in the depth of seed introduction, the engagement of the soil lumps was approximately 2.5 times greater than in the first trial variant. The soil moisture content was similar in both variants.

In the first variant, when the soil profile was measured after the narrow disk pressure roller had passed, it was concluded that it left a uniform bottom of the furrow; the depth fluctuations were 3 mm (Fig. 2 a). All the sugar beet seeds were pressed into the furrow bottom by 3–4 mm. The seed contact with the soil was good. After the disk-type pressure roller with fingers passed through the soil surface, the furrow bottom was found to have waves. The wave height was from 4 to 8 mm; the distance between the pressure centres of adjacent fingers was from 26 to 28 mm. The seeds were pressed into the furrow bottom at 1–3 mm. Some seeds (about 40%) were buried under the lump soil layer of 5 mm after the disc-type pressure roller with fingers passed.

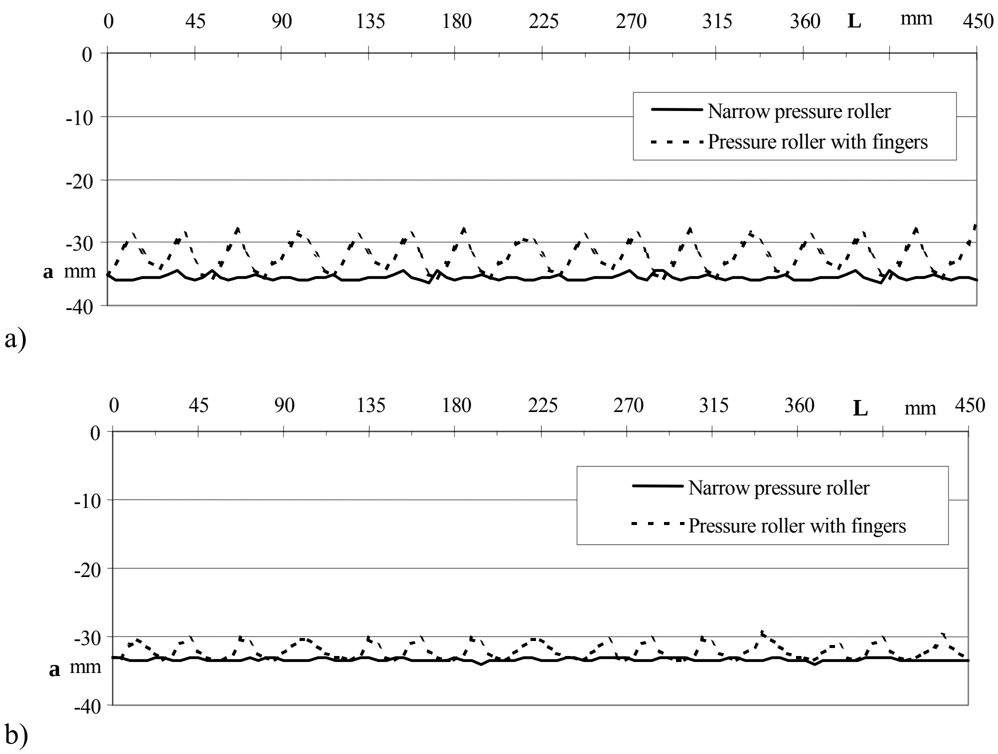


Fig. 2. The furrow bottom profile after the pressure roller passed through the soil surface: *L* is the furrow length, mm; *a* is depth, mm; a) I variant; b) II variant.

Table 2. The impact of the pressure roller design on the furrow bottom hardness.

Depth, mm	Soil hardness, MPa					
	Disk-type narrow pressure roller		Disk-type pressure roller with fingers			
			At the hollow		At the convexity	
	I variant	II variant	I variant	II variant	I variant	II variant
2	0.27±0.01	1.01±0.01	0.22±0.01	0.86±0.01	0.07±0.04	0.15±0.03
10	0.65±0.02	1.42±0.03	0.51±0.02	1.09±0.03	0.31±0.05	1.03±0.04
20	0.95±0.04	2.10±0.04	0.79±0.05	1.68±0.06	0.75±0.05	1.52±0.06

In the second variant the disk-type narrow pressure roller introduced the seeds into the furrow bottom at 2–3 mm; the furrow bottom was even (Fig. 2 b). A disc-type pressure roller with fingers pressed the seeds as in the first variant, i.e. 1–3 mm into the furrow bottom, but only 25% of the seeds was buried. The furrow bottom was wavy, and the wave height was up to 5 mm. In the first variant when the narrow pressure roller had passed, the hardness of the furrow bottom at the depth of 2 mm was on average 0.27 MPa; at the depth of 10 mm it was 0.65 MPa, and at 20 mm depth it was 0.95 MPa. The finger-type pressure roller pressed the furrow bottom less than the narrow one In addition, the hardness of the furrow bottom hollows and bumps or convexities was different (Table 2).

In the second variant when the narrow pressure roller passed, the hardness of the furrow bottom in the depth of 2 mm was 1.01 MPa; at depth 10 mm, it was 1.42 MPa, and, at depth 20 mm, it was 2.10 MPa. After the finger-type pressure roller passed, the hardness of the furrow bottom at the hollow at the depth of 2 mm was by 0.71 MPa greater than at the convexity. At depths of 10 mm and 20 mm these differences were insignificant. The dependence of the gravitational force on the construction of pressure roller and the movement speed was determined for both variants (Table 3).

Table 3. The relationship of the gravitational force with the design of the pressure roller, its movement speed and soil hardness.

Repeat number	Gravitational force, kN							
	Disc-type narrow pressure roller				Disc-type pressure roller with fingers			
	Soil hardness, MPa							
	0.4		0.9		0.4		0.9	
	The movement speed of pressure roller, m s^{-1}							
	1.39	1.94	1.39	1.94	1.39	1.94	1.39	1.94
1	0.672	0.661	0.710	0.741	0.753	0.807	0.744	0.835
2	0.693	0.673	0.648	0.665	0.728	0.736	0.778	0.763
3	0.671	0.649	0.691	0.688	0.716	0.774	0.836	0.793
4	0.659	0.695	0.704	0.705	0.756	0.792	0.748	0.789
5	0.691	0.711	0.667	0.643	0.773	0.782	0.673	0.788
6	0.650	0.652	0.694	0.692	0.730	0.709	0.761	0.689
7	0.656	0.642	0.701	0.699	0.742	0.801	0.812	0.813
8	0.689	0.652	0.693	0.641	0.803	0.765	0.783	0.799
9	0.581	0.653	0.601	0.676	0.823	0.746	0.813	0.696
10	0.666	0.695	0.648	0.653	0.782	0.753	0.774	0.772
x, kN	*0.663*	*0.668*	*0.676*	*0.680*	*0.761*	*0.767*	*0.772*	*0.774*
σ, kN	*0.032*	*0.024*	*0.034*	*0.031*	*0.035*	*0.031*	*0.046*	*0.047*
V, %	*4.89*	*3.58*	*5.10*	*4.59*	*4.54*	*4.04*	*5.92*	*6.10*
Sx,%	*1.55*	*1.13*	*1.61*	*1.45*	*1.43*	*1.28*	*1.87*	*1.93*

Note: *x* is average; *σ* is standard deviation; *V* is variance coefficient; *Sx,* is the average accuracy.

In the first variant the section of sugar beet with the narrow pressure roller had to be drawn at the speed of 1.39 m s^{-1} with the force of 0.663 kN, and at the speed of 1.94 m s^{-1} at the force of 0.676 kN. When the finger-type pressure roller was drawn at the speed of 1.39 m s^{-1} the force was 0.098 kN; when the speed was 1.94 m·s^{-1}, the force had to be greater by 0.099 kN. In the second variant when the section with the finger-type pressure roller was used at the speed of 1.39 m s^{-1}, the force was 0.096 kN, and at the speed of 1.94 m s^{-1}, the greater force 0.094 kN was needed as compared with the narrow pressure roller.

CONCLUSIONS

When the sugar beet is sown into uncultivated soil the pressure rollers should be adjusted on hinges so that the pressure on the soil would depend only on their gravitational force. The diameter of the pressure roller should be not less than 180 mm.

The narrow disk-type pressure roller with a 220 mm diameter, a 15mm width, and a mass of 1.4 kg presses the sugar beet seeds at 3–4 mm (i.e. through the whole seed thickness) into the soil with the force of 0.4 MPa, and into the depth of 2 to 3 mm into the soil which registers a hardness of 0.9 MPa.

The disk-type pressure roller with fingers consists of two disks (the disk diameter is 340 mm, the angle between the discs is 20^{o}) with 17 fingers each, which press the sugar beet seeds into the depth of 1 and 3 mm with the force of 0.4 and 0.9 MPa and make waves on the furrow bottom.

The narrow pressure roller in the 0.4 MPa hard soil pressed the furrow bottom at the depth of 2 mm (in the layer of seed in contact with the soil) with a force that was greater by about 0.05 MPa than the finger-type pressure roller at the hollows, and greater by 0.2 MPa at the convexities, and in the 0.9 MPa hard soil, accordingly, with greater forces 0.15 MPa and 0.86 MPa, respectively.

A sugar beet drill section with a narrow pressure roller should be drawn with the force of 0.663 kN when the soil hardness is 0.4 MPa and the speed is 1.39 m s^{-1}. When the disk-type pressure roller was used the force was 0.761 kN; when the section with the narrow pressure roller was drawn at the speed of 1.94 m s^{-1} the force was 0.668 kN; and when the finger-type pressure roller was used, 0.767 kN force was required. For the drill section with the narrow pressure roller used in the 0.9 MPa hard soil at the speed of 1.39 m s^{-1}, the 0.676 kN force was used, for the finger-type pressure roller – the force of 0.772 kN, at the speed of 1,94 m s^{-1}, when the narrow pressure roller was used – the force was 0.680 kN, and when the finger type pressure roller was used the force of 0.774 kN was required.

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