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Impact of technical parameters on the horizontal resistance component when slicing soil with a duckfoot share

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Abstract: *Impact of technical parameters on the horizontal resistance component when slicing soil with a duckfoot share.* The aim of the paper was studying the resistance during splicing of soil, represented by the horizontal resistance component (F_x), depending on changes of speed and working depth of a work piece in form of a duckfoot share. The study was realized under laboratory conditions in a soil channel which ensured repeatability of results. The tested work piece was a duckfoot share with width of 135 mm installed on a spring tine type VCO with stiffness of 8.3 kN·m^{-1}. The tests utilized two working depths for the tool: 0.03 and 0.05 m and two working speeds: 0.84 and 1.67 m·s^{-1}. Changes in the horizontal resistance component (F_x) depended on the speed and the working depth. At constant parameters of the soil and the tool, change in working depth from 0.03 to 0.05 m resulted in increase of resistance by 42.6% for the working speed v_1 = 0.84 m·s^{-1} and 58.8% for v_2 = 1.67 m·s^{-1}.

Key words: working resistance, soil, duckfoot share

INTRODUCTION

The key function of work pieces that operate in the soil is creation of optimal conditions for growth and development of plants [Chandon and Kushwaha 2002, Al-Suhaibani and Ghaly 2010, Buliński and Sergiel 2013]. Apart the qualitative effect, a key assessment criterion for operation of a given work pieces or their assemblies is the energy intensity of the process itself [Buliński et al. 2009]. The value of load related to operation of the work piece in the soil is determined by a number of factors related to: construction parameters of the tool, characteristics of the soil and the agro-technical parameters of the process [Lejman and Owsiak 2001, Buliński and Sergiel 2011, 2014, Lejman et al. 2013, Powałka and Buliński 2014a, 2014b]. For processes aimed at loosening the soil in its deeper layer it is advisable to use narrow tools (63–125 mm). When the aim is to loosening the upper soil layer with low energy expenditures the recommendation is to use wide tools (125–200 mm) [McKyes 1984]. An important criterion when dividing the tools into wide and narrow ones is the depth/width ratio [Godwin and O'Dogherty 2007]. If the ratio is less than 0.5 the tool is considered wide (knife, duckfoot share) and with larger ratios the tools are considered narrow (coulters, shares).

Analysis and interpretation of results obtained from empirical field tests is extremely difficult due to high variability of conditions in which the tests are performed. Therefore, it is typical to perform testing under laboratory conditions that allow for controlled testing conditions and legitimate conclusions [Piotrowska and Klonowski 1996, Sahu and Raheman 2006a, 2006b, Javadi et al. 2012]. On basis of the experimental testing is possible to discover the phenomena that occur during the operation of the work pieces in the soFig. We collect information that allows us to foresee significant parameters, characteristic for the obtained soil deformation such as depth and distance in the direction of the work piece's movement. On basis of the data gathered it is possible to develop models that allow for forecasting the resistance forces for a wide selection of tools [Kuczewski and Piotrowska 1998, Godwin and O'Dogherty 2007, Zaied et al. 2014].

The cultivation tools or equipment are also widely used for cultivation of plants in row-crops. The key aim of cultivation by row-crops is shallow loosening of soil between the rows of plants, which removes weeds, breaks crust, facilitates water ingress and aerates the soil, makes water evaporation more difficult and earthing-up the plants in order to ensure their better growth. Such cultivation results in better growth and development conditions for the plants and removes weeds that hider growth of the desired arable plants – being their direct competitors. Earth crust or compression makes air ingress difficult and hampers proper development of plants and the weeds, which are better adapted to local conditions, grow quicker and deprive the arable crops of water, nutrients and sun. This area yields less publications, especially in relation to energy load caused by the soil on the duckfoot share with low rake angle. This is also due the fact that maintaining the assumed, low working depth of such a tool is much more problematic than for the tools operating deeper – as in their case the relative error is smaller.

The aim of the paper was studying the resistance during splicing of soil, represented by the horizontal resistance component (F_x), depending on changes of speed and working depth of a work piece in form of a duckfoot share.

MATERIAL AND METHODS

In order to experimentally determine the impact of operating conditions on a shallow-operation work piece on the horizontal resistance component when slicing soil realized were model tests in a soil channel.

The main components of the soil channel is a steel half-pipe – 10 m long and 2 m wide – created to test models of actual agricultural work pieces and equipment of typical size. A track is attached to the edge of the half-pipe on which the tool trolley moves. The trolley is powered by an electric motor via a regulator, drive shaft and dual line system that allows for moving the trolley in both directions. The motor is controlled by an electronic circuit allowing for linear control of the work speed of the tool trolley. During preparation of the soil for testing the trolley is equipped with special stiff loosening tines, next levelling blade and during the last pass a smooth compressing cylinder where the compression strength may be controlled (Fig. 1). This system allows for loos-

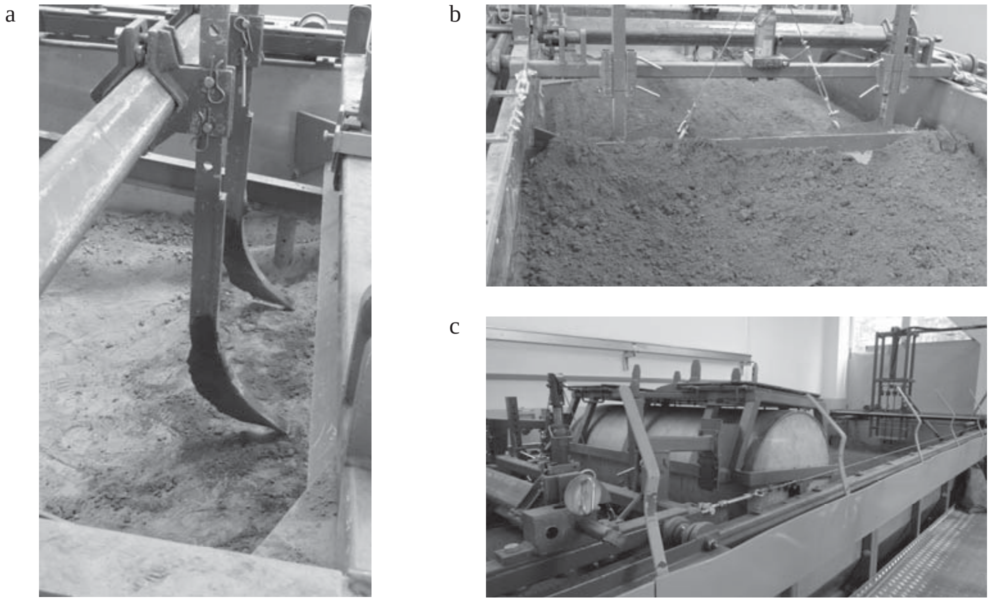

FIGURE 1. The stages of soil preparation for testing: a – loosening tines, b – levelling blade during work, c – compression of soil by a smooth cylinder

ening and preparing the soil before the actual measurements [Miszczak and Nowakowski 2006, Buliński et al. 2010]. The tests were realized in the channel filled with fine sand clay with the following characteristics: sand 61.5%, ash 22.0%, silt 16.5% [PN-R-04033]. The humidity of the soil was controlled using drying––weighting method in accordance with the requirements of the PN-ISO 11465:1999; in conversion to the weight of moist soil and it was 10.1 ±0.45%. The soil was loosened down to 0.22 ±0.02 m at speed of 0.33 ±0.01 $m \cdot s^{-1}$. After levelling it with a blade it was later compressed with the cylinder during two passes. The weight of the cylinder during the first pass was 360 kg, and 520 kg during the second pass. Soil compaction was controlled by a cone penetrometer with angle of 30° and diameter of base of 20.27 mm, manufactured in accordance with the norm ASAE 313.2. The measured average – measurements made before each test measurement in randomly chosen five locations of the channel, was 486 ±5 kPa. The utilized system ensured repeatability of conditions during subsequent test passes.

Using the prepared soil, realized were measurement passes by the tool trolley with a bar to which attached was an adepter with the work tooth. Between the adepter, which allowed for changing the operating depth of the duckfoot share, a three-directional force sensor CS3D was installed (Fig. 2). The sensor allowed for recording of resistance experienced by the work piece in the three perpendicular directions: F_x – in line with the speed vector, F_y – perpendicular to the speed vector in plane perpendicular to the surface of the soil and F_z – perpendicular to the speed vector in plane parallel to the

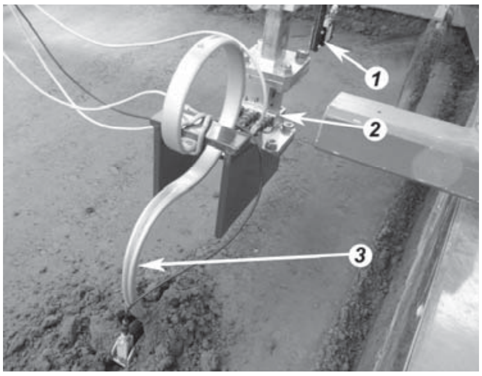

FIGURE 2. Work piece during measurement: 1 – laser sensor LDS 100-500P-S, 2 – three-directional force sensor CS3D, 3 – trident with a duckfoot share

surface of the soil. Due to stiff connection of the work piece, the working depth was monitored in a continuous manner using laser sensor LDS 100-500P-S manufactured by Beta Snsorik. The tested work piece was a duckfoot share with width of 135 mm installed on a spring tine type VCO with stiffness of 8.3 kN·m^{-1} (Fig. 3). The tests utilized two working depths for the tool: d_1 = 0.03 and d_2 = 0.05 m, and two operating speeds: v_1 = 0.84 and v_2 = 1.67 m·s^{-1}.

FINDINGS AND DISCUSSION

Due to the manner in which the work piece was mounted, the appropriateness of assumptions were tested, in relation to maintenance of the set depth in individual test passes. On basis of a performed a two-factor variance estimation (speed and depth), it was established that the actual work depth did not change with the change of the operating speed ($F_{v1=1,\ v2=2079}$ = 2.12, with critical significance level p = 0.1456), which proves the repeatability of the parameters of the duckfoot share. The operating depth was differentiated for the set depth levels ($F_{v1=1,\ v2=2079}$ = 603.50, p < 0.0001), which means that the selected parameters of 0.03 and 0.05 m resulted in larger inter-group differences than dispersion of values for a given depth (intra-group dispersion). The operating depth change coefficient for v_1 = 0.84 m·s^{-1} was 1.97% and for v_2 = 1,67 m·s^{-1} was 1.70% which indicates a negligible variation of operating depth. The maximum relative error did not exceed 2.1%. Therefore we can

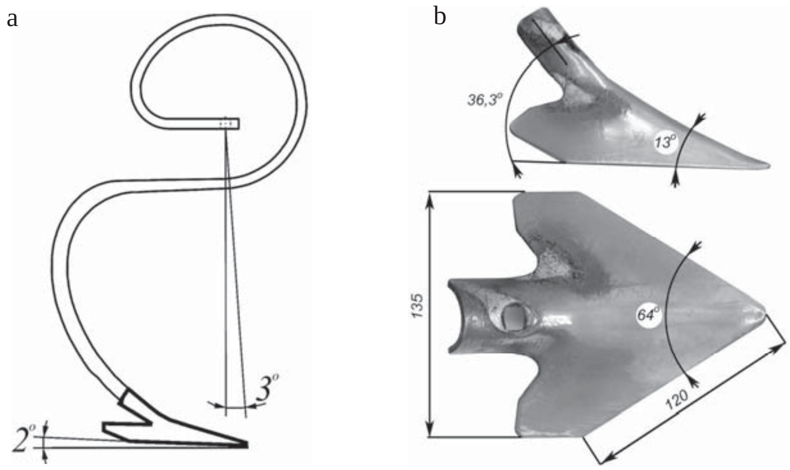

FIGURE 3. Tooth with duckfoot share: a – mounting parameters of the spring tine type VCO, b – parameters of the duckfoot foot share

assume that the two set operating depths of 0.03 and 0.05 m were maintained during the test procedure regardless of the speed of the test. The realized analysis serves as a proof of repeatability of the measurement tests.

During the test proper, instantaneous force values were recorded with frequency of 50 Hz. A specimen of work resistance component (F_x) for duckfoot share 135 mm operating at depth d_2 = 0.05 m, at two movement speeds: v_1 = 0.84 and v_2 = 1.67 m·s^{-1} (Fig. 4).

In order to check the significance of variability of the working resistance component (F_x) at different test settings, a two-way variance analysis with repetitions was realized (Table 1). The variability of the work resistance component (F_x) was statistically significant for the changes in speed and depth of operation and for their interaction (Fig. 5).

For speed v_1 = 0.84 m·s^{-1} and operating depth 0.03 m the working resistance component (F_x) reached on average 154.7 N (Table 2). Increasing the operating depth by 10 mm, within the studied depth range, resulted in increase of resistance by 33 N. At operating depth of 0.05 m the resistance component (F_x) was 220.6 N. Analogous to the speed v_1 also for speed v_2 the resistance in-

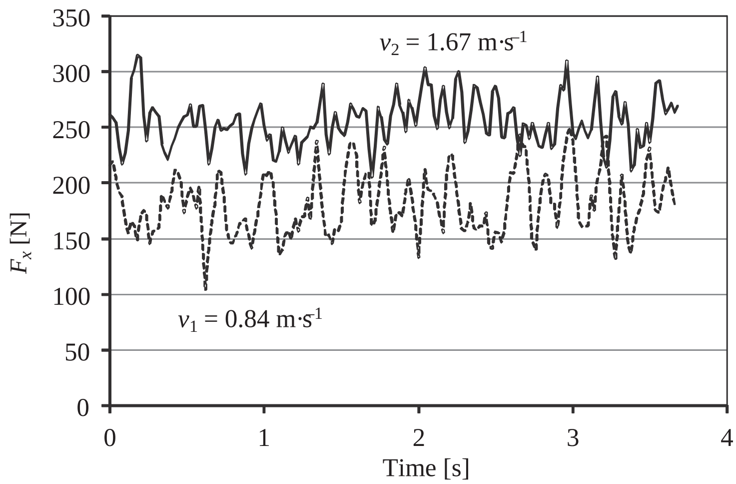

FIGURE 4. A specimen of work resistance component (F_x) for duckfoot share 135 mm operating at depth d_2 = 0.05 m at two movement speeds v_1 = 0.84 m·s^{-1} and v_2 = 1.67 m·s^{-1}

TABLE 1. Variance analysis of factors impacting the value of working resistance component (F_x)

Source variable	Total squares	Number degrees of freedom	Average square	Value statistics (F_{obl})	Critical significance level
Speed: v	15,852.8	1	15,852.8	10.68	0.0011
Depth: d	$2.6905 \cdot 10^6$	1	$2.6905 \cdot 10^6$	1,813.34	<0.0001
Interaction $v \times d$	55,029.7	1	55,029.7	37.09	<0.0001

Source: Own results of the authors.

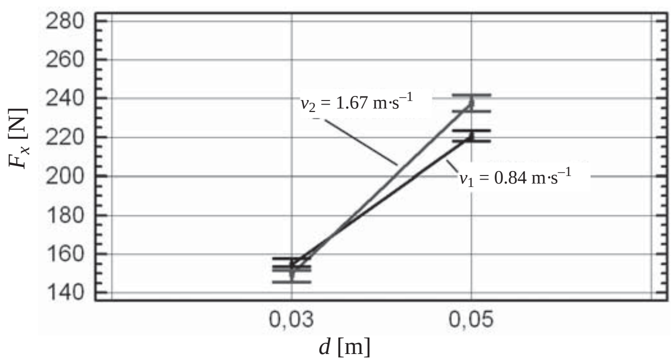

FIGURE 5. Changes in value of resistance (F_x) depending on the operating depth (d) for two operating speeds (v)

creased with the increase of depth, but their value was higher and amounted to 44 N per 10 mm. Change in working depth from 0.03 to 0.05 m resulted in increase of resistance by 42.6% for the working speeds v_1 = 0.84 m·s^{-1} and 58.8% for v_2 = 1.67 m·s^{-1}. Field tests of cultivator teeth equipped with duckfoot shares indicate an increase in resistance of 59.61% in horizontal plane when changing the operating depth from 8 to 10 cm [Frid et al. 2004]. During operation of a tool in shape of a symmetrical diagonal wedge with width of 0.14 m and a lead angle of 30° at operating speed of 2 m·s^{-1} in a soil of middle clay, the change of depth from 0.04 to 0.06 m resulted in increase of operating resistance (F_x) by 30% [Lejman 2005]. For a straight wedge with width of 0.14 m and analogous operating conditions, increasing the operating depth by 0.02 m resulted in resistance (F_x) by 42%.

Change of operating speed, in the tested range, had less impact on the change of resistance than the operating depth. For the depth of 0.03 m, change of operating speed resulted in a small drop of resistance by 3% which is within the statistic error. At speed v_2 observed was increase by the resistance component (F_x) by about 8%. Due to operation of the tool in the soil, created are new shear stresses. In the layer, where the stresses are the strongest and the shear resistance of the soil is exceeded, the layer is spliced [Bernacki 1981]. The manner in which the work tool operates is a cycle in which deformations are introduced until the earth breaks due to transfer of stresses into the structure of the soFig. Changes in the values of the resistance are presented on Figure 4, which represents the cycle of increased resistance of the soil, deflection of the tooth with the duckfoot share and next, after the earth parts and is cast aside, the tooth moves forward into already loosened earth where it experiences less resistance, which is registered by the sensor as lower value of the horizontal resistance component F_x. The cycle of operation also results in changes to the longitudinal profile of the bottom of the furrow. During the study it was noticed that the higher the change of the resistance component (F_x) (increased tooth deflection) the larger the unevenness of the furrow's bottom. This effect is desirable from agro-technical standpoint as it allows for smaller soil erosion as it limits surface run-off. The coefficient of variation of operating resistance component (F_x) is a function of changes in load. The above value of coefficient indicates higher changes in the resistance force (Table 2). Taking into consideration the test results it should be stated that for smaller depths we will achieve a larger effect of limiting the surface run-off of water. This however requires additional specialized research.

TABLE 2. Value of resistance component (F_x) for the studied variables

Depth working [m]	Speed working [m·s^{-1}]	Work resistance component (F_x) [N]				Standard deviation [N]	Coefficient of variation [%]
		min	max	average	median		
0.03	0.84	9.2	287.0	154.7	159.2	46.2	29,8
	1.67	63.1	252.4	149.6	151.0	32.2	39.4
0.05	0.84	103.1	314.5	220.6	222.9	37.6	17.1
	1.67	155.4	313.4	237.6	237.5	28.6	12.1

Source: own results of the authors.

Increasing the operating speed results in the stresses being concentrated near the edges of the work piece and decrease the transfer of stresses into the structure of the soFig. This is reflected by the values of standard deviation which in the two tested depths are lower for the higher tested operating speeds. At the same time for higher operating depth there is also increased uniformity of the load. Owsiak et al. [2006] when comparing the average slicing resistance values and instantaneous values stated that for operating depth of 0.07 m the relative differences reached 20% whereas for 0.12 m only 5%. In the field testing of cultivator teeth a change in speed within range from 1.64 to 3.16 m·s^{-1} resulted in resistance increase of 53.11% in the horizontal plane [Frid et al. 2004].

The most favourable work system for tools in shallow operation is aiming at maintaining, with the largest degree of precision, of low operating depth. This should ensure proper cutting of weeds' roots and will result in decreased operating resistance. At the same time it allows for utilization of higher operating speed (from the agro-technology ranges) that have less impact on power requirements.

CONCLUSIONS

1. For fixed soil and tool parameters, increase in operating depth between 0.03–0.05 m and operating speed from 0.84 to 1.67 m·s^{-1} had statistically significant impact on the changes of value of the operating resistance component (F_x). Interaction between these factors was also statistically significant.
2. During soil splicing using the duck-foot share, the higher gradients of the operating resistance component (F_x) were observed for changes in the operating depth from 0.03 to 0.05 m and operating speed v_2 = 1.67 m·s^{-1} (44 N for every 10 mm of depth) than

for v_1 = 0.84 m·s^{-1} (33 N per every 10 mm of depth).
3. Temporary changes of operating resistance of duckfoot share operating in the soil are smaller for higher operating speed and with increased depth the load becomes more uniform.
4. The realized research indicates the need to analyze the surface of the bottom of the furrow depending on the parameters of the duckfoot share. Increased lack of longitudinal conformity will allow limiting the surface erosion of the soil due to limited run-off of water between the rows.

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Streszczenie: *Wpływ parametrów technicznych na składową poziomą oporów skrawania gleby gęsiostopką.* Celem pracy było zbadanie oporu skrawania gleby, reprezentowanego przez poziomą składową oporów (F_x), w zależności od zmian prędkości i głębokości roboczej dla elementu roboczego w postaci gęsiostopki. Badania przeprowadzono w warunkach laboratoryjnych w kanale glebowym zapewniającym powtarzalność wyników. Badanym elementem roboczym była gęsiostopka o szerokości konstrukcyjnej 135 mm zamocowana na zębie sprężystym typu VCO o sztywności 8,3 kN·m^{-1}. W badaniach stosowano dwie głębokości robocze narzędzia: 0,03 i 0,05 m, oraz dwie prędkości robocze: 0,84 i 1,67 m·s^{-1}. Zmiany wartości składowej poziomej oporów (F_x) zależały od prędkości i głębokości roboczej. Dla stałych parametrów gleby i narzędzia, zmiana głębokości roboczej z 0,03 do 0,05 m spowodowała przyrost oporów o 42,6% dla prędkości roboczej v_1 = 0,84 m·s^{-1} i 58,8% dla v_2 = 1,67 m·s^{-1}.

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