Full Length Research Paper

The effects of working parameters and tillage quality on rotary tiller specific work requirement

Ondrej Ponjican[1]*, Andjelko Bajkin[1], Aleksandra Dimitrijevic[2], Lazar Savin[1], Milan Tomic[1], Mirko Simikic[1], Nebojsa Dedovic[1] and Miodrag Zoranovic[1]

[1]Department of Agricultural Engineering, Faculty of Agriculture, University of Novi Sad, 21000 Novi Sad, Republic of Serbia.
[2]Faculty of Agriculture, University of Belgrade, Nemanjina 6, Belgrade, Republic of Serbia.

The aim of this paper was to analyze the influence of rotary tiller rotor rotation direction on specific work requirement (SW_{PTO}). The SW_{PTO} was calculated by measuring the power take-off (PTO) torque, PTO speed, working speed and depth, as well as the working width. The tillage quality was determined by the bulk density and soil structure. Reverse rotor rotation direction concept is characterized by more efficient tillage which provides significantly higher amount of macro-structure aggregates (0.25 to 10 mm) and their better distribution in the soil. Significantly lower SW_{PTO} was observed with the reverse rotor rotation direction. It was within the range of -2.15-27.74% (14.35% on average) depending on the work speed which was 0.29 to 1.08 m s^{-1}. Multiple linear regression provided new equations for the calculation of SW_{PTO} depending not only on the working parameters, but on the intensity of soil breaking and soil conditions as well. The obtained equations had high values of Coefficients of determination R^2 (0.92 to 0.99 for conventional and 0.84 to 0.93 for reverse rotor rotation direction). Reverse rotor rotation direction had lower SW_{PTO} values which were 20.3 and 15.5% for the working speeds of 0.5 and 1.0 m s^{-1}, respectively, and were obtained for equal values of tillage intensity parameters.

Key words: Tillage, rotary tiller, specific work, bulk density, soil structure.

INTRODUCTION

The research on the tillage influence on the physical, as well as the micro-biological properties of the soil was mainly conducted with the aim of natural resources preservation (Lal, 2000; Sakin et al., 2011). Moreover, since crop growth and productivity are a reflection of soil quality, any degradation of the soil can be expected to adversely affect the stability of system (Van Dang, 2007).

In the production of root vegetables, high yield and high quality of root morphological properties can be achieved only from intensely tilled soil (Rubatzky et al., 1999; Lazic et al., 2001; Djurovka, 2008.). The required level of tillage quality can be achieved only by using complex agricultural machinery (bed and ridge former) with main tillage tool having the form of a rotor, as in a rotary tiller (Bajkin et al., 2010; Ponjican et al., 2008). Deciding on the optimal work regime of a rotary tiller rotor, soil tillage can be performed with the lowest specific work requirement (Kosutic et al., 1997), and negative influence of rotary tiller rotor on soil degradation can be minimized (Matjašin et al., 1988; Ponjican et al., 2011).

Today, rotary tillers with conventional rotor rotation direction are most commonly used. Earlier, detailed researches on the intensity of soil breaking and tillage quality, which depended on the conventional rotary tiller construction and its working parameters, have been conducted. One way to optimize rotary tiller working

---

*Corresponding author. E-mail: ponio@polj.uns.ac.rs.

parameters is to define the mean diameter of the soil clods (Kosutic et al., 1997). Kheiralla et al. (2004) have determined the linear dependence between power requirements and working or PTO speed. Sümer et al. (2010) have studied the fuel consumption and power distribution between tractors and PTO driven machines. Numerous researchers have been focused on the determination of the optimal shape of blade. Saimbhi et al. (2004) developed a rotary tiller blade using tree-dimensional computer graphic with the aim of eliminating the contact between the blade's surface and untilled soil. Asl and Singh (2009) have developed a mathematical model for the required power by using static and dynamic forces in order to determine the blade's shape. The blade was tested in the laboratory conditions and its specific work requirement, regarding the velocity ratio, and blade bite length were determined. So far, the methodologies for the analyses of energy consumption and specific work requirement during the tillage have not included the basic tillage quality parameters given by the intensity of soil breaking.

On the other hand, only few studies include the research into the reverse rotor rotation direction. If geometry and kinematics are analyzed, rotary tiller with reverse rotor rotation direction presents a better solution regarding the ridge height and maximum soil slice width (Celik and Altikat, 2008). There are different opinions in the literature concerning the effects of rotor rotation direction on tillage quality and energy consumption. Matjašin et al. (1988) and Páltik et al. (2003) imply that in the case of reverse rotor rotation direction more energy is consumed in tillage because of the higher speed and cutting length. That was concluded based on the observation of soil as a homogenous material. Salokhe and Ramalingam (2001; 2003) have discovered that, in the case of reverse rotor rotation direction, the cutting principle is completely changed, thus affecting the soil resistance and quality of soil breaking. More detailed description of the cutting process of rotary tiller with reverse rotor rotation direction during the tillage is given by Kataoka and Shibusawa (2002). They have discovered high frequency oscillations corresponding to the cracking of soil during the cutting which influences the cutting resistance of the soil. In the laboratory conditions, Lee et al. (2003) measured 20 to 30% lower values of torque for reverse rotor rotation direction. Salokhe and Ramalingam (2003) examined the influence of rotor rotation direction on the PTO power consumption, depending on the working speed. Those investigations were conducted in the field conditions. The same authors recorded 14 to 34% lower value of the PTO power consumption and better tillage quality, with reverse rotor concept in the field conditions. During the mentioned research (Salokhe and Ramalingam, 2003), two rotary tillers of different constructions were compared. They had different rotor rotation directions and were equipped with different types and shapes of the blades (C-type and

scoop blades). Therefore, that study does not offer precise assessment of the influence of rotor rotation direction on PTO power consumption because of the influence of the blade's shape.

Previous studies only mention different PTO torque and PTO power, without specifying any mathematical equations for SW_{PTO} for both rotor rotation concepts. SW_{PTO} analysis is more precise because it includes influence of the working speed and working depth. In order to determine more accurately the influence of rotary tiller rotor rotation direction on the tillage quality and SW_{PTO}, it is necessary to perform a detailed research that would include different soil conditions and different working parameters with no changes in the construction of the machinery or shape of the blades.

At the beginning of this research, an extensive investigation on the tillage quality was conducted with rotary tiller for both rotor rotation directions depending on the working speed, working depth and soil conditions. For the purpose of this study specific work requirement (SW_{PTO}) for soil tillage and fuel consumption (Q_{PTO}) were also determined. By using Nonlinear regression analysis the equations for the calculation of SW_{PTO}, depending on the working speed, were obtained. Due to the low values of Coefficients of determination (R^2), additional parameters had to be introduced in the investigation. Those parameters were obtained by the correlation and Path analyses, which determined a statistically significant influence of working regime, tillage intensity and soil conditions on SW_{PTO}, depending on the rotor rotation direction of rotary tiller. Multiple linear regression was used for the determination of the equations for SW_{PTO} for statistically significant parameters, depending on the rotor rotation direction. The main goal of this research was to determine quantitatively the influence of rotary tiller rotor rotation direction for the given values of working parameters, tillage intensity and soil conditions, and also to specify the use of rotary tiller with reverse rotor rotation direction.

MATERIALS AND METHODS

Experimental site and machinery

Field testing was carried out in 2008 in the climatic conditions of Northern Serbia region (45.21°N, 19.45°E). The type of soil was chernozem. The soil specific bulk density was 2.59 g cm^{-3} and it consisted of 1.2% send, 36.88% silt, 43.48% dust and 18.44% clay. Parcels were considered as the repetitions: Parcel 1 (stubble field); Parcel 2 (soybean field) and ; Parcel 3 (ploughed field).

Every parcel was divided in twelve equal sub-parcels 3 m wide and 150 m long. On each sub-parcel, rotary tiller was tested for five different working speeds starting from the lowest gear. Classic 1.3 m wide rotary tiller with 30 blades per rotor was used in the experiment. Rotor diameter was 0.5 m with 153 min^{-1} speed and 3 L-type blades (Figure 1) on one side of the flange. The distance between the flanges was 0.26 m. The hood was extended at the front so the overall angle around the rotor was 132° and its trailing screen was in the upper position during the testing. The nominal
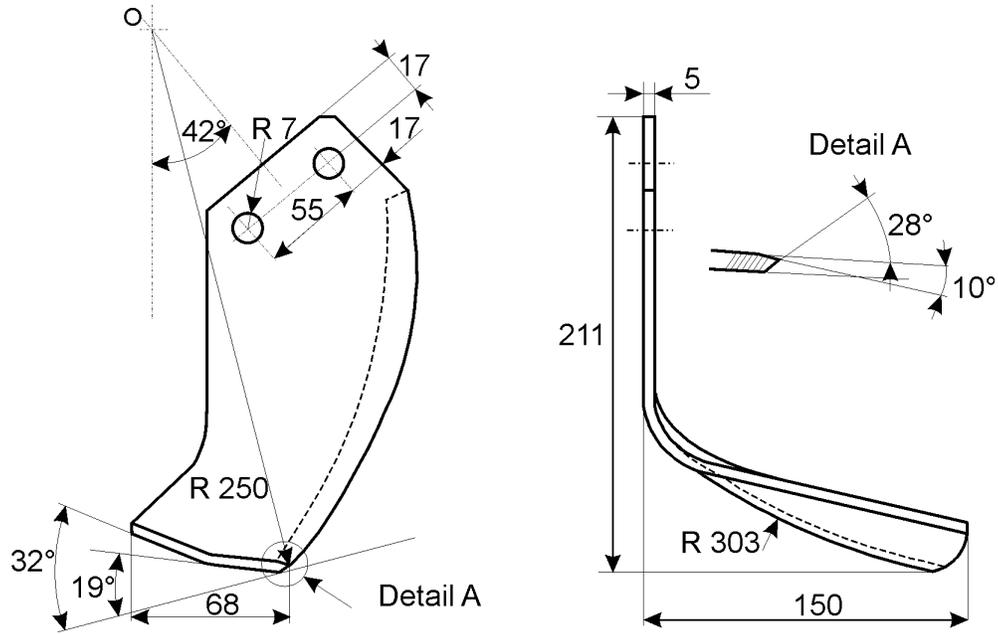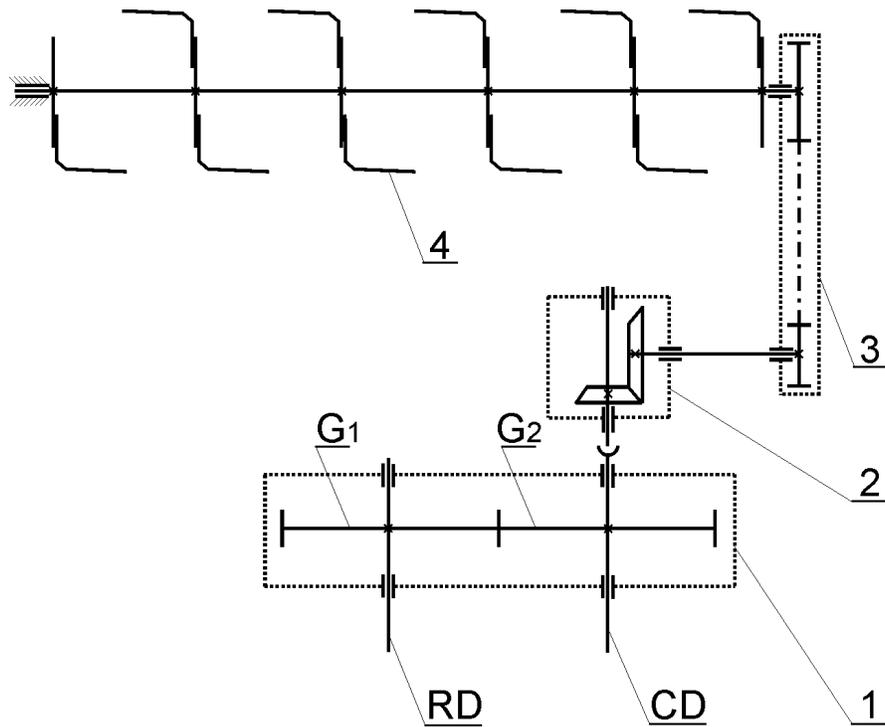
Figure 1. Shape of the blade L-type.

Figure 2. Adaptation of rotary tiller: 1-inverter; 2-gear transmission; 3-chain transmission; 4-rotor.

power of the used tractor was 49 kW. An adaptation was made by adding the inverter (two gears) that would enable the reverse rotation direction of the rotor (Figure 2).

Sampling and measurements

The experiment was carried out as a three-factorial experiment and

it was organized as randomized block design: Factor 1: Rotor rotation direction (conventional rotor rotation direction (CD) and reverse rotor rotation direction (RD)); Factor 2: Working speed (five different working speeds, starting from the lowest gear) and; Factor 3: Depth (upper layer (U) 0 to 5 cm depth and lower layer (L) 5 to 10 cm depth).

The experiment for the specific work requirement (SW_{PTO}) and fuel consumption (Q_{PTO}) determination with respect to the working parameters (Factors 1 and 2) was carried out as a two-factorial block design. The influence of working parameters (rotor rotation direction and working speed) and depth was evaluated by measuring the following basic physical soil properties (Horn, 1990; Balesdent et al., 2000): bulk density (BD), structure coefficient (k) and moisture content (w). All these were measured prior to (PT) and after (AT) the tillage. Parcels 1 and 2 had 0.6 to 0.85 kg m^{-2} of plant residues, which is in accordance with the conditions stated by Salokhe and Ramalingam (2003).

For the measurement of the physical soil properties, as well as the SW_{PTO} and Q_{PTO}, standard methodology and equipment of accredited laboratory (ISO/IEC 17025) were used. Soil testing samples were taken in six repetitions from disturbed soil and in natural condition (ISO 10381-6). The moisture content and bulk density were measured at the depths of 0-5 cm and 5-10 cm with 100 cm^3 cylinders. The soil structure analysis was performed by the sieves according to the dry sieving method (Salokhe and Ramalingam, 2001; Lee et al., 2003; Keller et al., 2007; Birkás, 2008; Petrović et al., 2010). The 2 kg samples were taken at the depths of 0-5 cm and 5-10 cm. The sieves were adjusted for the rotary tiller testing and had the dimensions of 10 and 0.25 mm. The soil structure was presented by the ratio of macro-structure aggregates (Birkás, 2008), that is by the structure coefficient k (Šein et al., 2001):

$$ k = \frac{m_{macro}}{m_{micro} + m_{mega}}, \qquad (\text{-}), \qquad (1) $$

Where: m_{macro} – macro-structure aggregates mass (g), m_{micro} – micro-structure aggregates mass (g), m_{mega} – mega-structure aggregates mass (g).

Theoretical speed was measured with the device installed on the tractor rear wheel. The working speeds were measured with a special trailer wheel. Both instruments were built-in Optocapler GP1A70R (Sharp) sensors (producer of device TRCpro, Serbia). The fuel consumption was measured by a flow-meter PLU 116H (Piergurg, Germany). Eight channel acquisition unit, Spider8 (HBM, Germany), connected to PC was used for the data collection and storage. For the PTO speed and PTO torque measuring, dynamometer TD2 (produced by TRCpro, Serbia) was used with the built-in plate Linear Technologies and sensor XY21-6/350 (HBM). The soil depth was measured with special constructed laboratory device (0.5 cm precision). Specific work requirement was calculated based on the Equation (2):

$$ SW_{PTO} = \frac{M \cdot n \cdot \pi}{30 \cdot V_f \cdot B \cdot a}, \quad (\text{Jm}^{-3}), \qquad (2) $$

Where: M – PTO torque (Nm), n – rotor speed (min^{-1}), V_f – working speed (m s^{-1}), B – working width (m), a – working depth (m). Specific work requirement (SW_{PTO}) represents the most frequently applied and most objective parameter that is used for the best assessment and selection of the appropriate implement

construction (Asl and Singh, 2009), or the entire machinery used for soil tillage (Páltik et al., 2003).

Influences of the rotor rotation direction on SW_{PTO} were determined by working parameters, intensity of soil breaking (tillage quality) and soil conditions. After the testing of simple correlation and Path's coefficients, statistically most significant independent variables were chosen:

Velocity ratio; $x_1 = \lambda = R\omega/V_f$ (-), $\qquad\qquad$ (3)

Where: R – rotor radius (m), ω – angular velocity (s^{-1}), V_f – working speed (m s^{-1}),

Ratio of bulk density prior to (BD_{PT}) and after the tillage (BD_{AT});

$x_2 = BD_{PT}/BD_{AT}$, (-), $\qquad\qquad$ (4)

Ratio of structure coefficient prior to (k_{PT}) and after the tillage (k_{AT});

$x_3 = k_{PT}/k_{AT}$, (-), $\qquad\qquad$ (5)

Soil moisture, $x_4 = w$ (%).

Statistical analysis

Statistical analysis was performed by Statistica 10 software package. All the testing had 5% significance threshold. ANOVA and Duncan's multiple range tests were used to determine the statistically significant differences between the analyzed parameters. Coefficients of determination (R^2) were calculated based on the nonlinear regression and multiple linear regression. The influence of the given (independent variables) treatments (x_n; n = 1; 2; 3 and 4) on the specific work requirement (y = SW_{PTO}) was tested by the simple correlation coefficients ($r_{y,xn}$) and standard regression coefficients, i.e. Path coefficients ($p_{y,xn}$), that were calculated by applying the Correlation matrices and Multiple Linear Regression. According to Li (1975), Path coefficients can precisely determine the direct effect of the independent variables (x_n) and indirect influence on dependent variable (y) via another independent variable.

RESULTS

Previous research (Ponjican, 2009) shows that the use of rotary tiller with reverse rotor rotation direction, which is in the range of 0.29 to 1.08 m s^{-1}, gives 1.34 to 2.99 times lower ridges and 12.38 to 42.08% longer cutting length. In order to determine, as clear as possible, the influence of reverse rotor rotation direction on the energy consumption and tillage quality, it is necessary to conduct a detailed investigation in the field conditions (Sakokhe and Ramalingam, 2003).

Soil conditions prior to the tillage

The testing of the soil conditions was performed before the tillage (PT, Table 1). Prior to the tillage, bulk density of the soil was 1.17 to 1.34 g cm^{-3} and the structure coefficient was 0.69 to 1.11 (Table 1). Regarding the tillage, Parcel 2 (soybean filed) had most unfavorable

Table 1. Soil physical properties prior to (PT) and after (AT) tillage depending on the rotor rotation direction*.

Parameter	Bulk density, BD (g cm^{-3})				Structure coefficient, k (-)			
	Parcel 1	Parcel 2	Parcel 3	Average	Parcel 1	Parcel 2	Parcel 3	Average
PT	1.29[a]	1.34[a]	1.17[a]	1.27[A]	1.07[b]	0.69[b]	1.11[c]	0.96[C]
AT CD	1.11[b]	1.08[b]	1.04[b]	1.07[B]	1.16[b]	0.93[b]	1.77[b]	1.29[B]
AT RD	1.11[b]	1.11[b]	1.06[b]	1.09[B]	1.75[a]	1.51[a]	2.10[a]	1.79[A]
Index1 = (PT-AT CD)/PT·100 (%)			15.75					34.38
Index2 = (PT-AT RD)/PT·100 (%)			14.17					86.46
Index3 = (CD-RD)/CD·100 (%)			-1.87					-38.76

*Duncan`s test by columns with the 5% significance threshold.

type of soil, which was determined based on the highest value of the bulk density (1.34 g cm^{-3}) and lowest value of the structure coefficient (0.69).

Conditions prior to the tillage were optimal regarding the soil moisture content (18.95 to 22.93%), because crumby structure is formed in conditions of 20 to 21% of moisture content and intensive soil braking appear in the conditions of 17 to 18% moisture content (Birkás, 2008).

The influence of rotary tiller use on physical properties of the soil

When tested, BD before (1.27 g cm^{-3}) and after the tillage (1.07 and 1.09 g cm^{-3}), significantly lower values were determined after the tillage (Table 1). After the tillage, BD values were 15.75% and 14.17% lower for conventional and reverse concept, respectively. Similar values were reported by Salokhe and Ramalingan (2001). They stated that BD was 16.21% lower after the tillage with conventional rotary tiller (C-type blades) while the use of rotary tiller with reverse rotor rotation direction (scoop blades) lowered BD by 14.52%.

When k was tested prior to tillage (0.96) and after the tillage (1.29 and 1.79), it showed significantly higher values after the tillage. As for the k, it could be observed that the average values were 34.38% higher after the tillage for the conventional rotary tiller, and considerably higher, for 86.46%, for the tiller with the reverse rotor rotation direction. Lee et al. (2003) have recorded even higher differences while measuring the ratio of soil braking in the laboratory. The same authors stated that after the conventional rotary tiller use, the ratio of soil braking was 95.30% higher, while after applying the tiller with reverse rotor rotation direction, this parameter was 110.91% higher.

The change of rotor rotation direction did not cause statistically significant differences in BD. In the case of conventional rotary tiller this value was 1.07 g cm^{-3} and with reverse rotation direction the BD was 1.09 g cm^{-3}. The value of BD for reverse rotor rotation was 1.87% lower when compared to conventional rotary tiller use. The similar results were reported by Salokhe and

Ramalingan (2001). They stated that the BD in the case of reverse rotor rotation direction (scoop blades) was 1.69% higher in comparison to the conventional rotary tiller concept (C-type blades).

More precise evaluation of tillage quality was achieved after the determination of structure coefficient (k). In the case of conventional rotary tiller k was 1.29, which was significantly lower compared to the reverse rotation concept when it was 1.79. The value of k for reverse rotor rotation was 38.76% higher in comparison to the conventional rotary tiller use. Therefore, more intensive tillage can be achieved with the implementation of rotary tiller with the reverse rotor rotation direction. Lee et al. (2003) recorded 95.30% higher ratio of soil braking with the reverse rotor rotation direction in the laboratory conditions.

The changes of the soil physical parameters (BD and k) were tested for both rotation directions of rotary tiller, depending on the gear and depth (Figure 3).

Soil physical properties (tillage quality) were tested for the second and fifth gear for the working speeds of 0.43 and 1.04 m s^{-1}. The increase in the working speed caused significantly higher values for BD when the fifth gear was applied to both conventional and reverse rotation concepts (Figure 3a). Tested k showed significantly higher values in the second gear in both rotor rotation direction concepts (Figure 3b). By increasing the working speed from the second to the fifth gear 6.73 and 3.74% higher values of BD and 17.73 to 18.78% lower values of k were measured, respectively. Better tillage quality was obtained by applying the second gear.

The increase of the depth from 0 to 5 to 5 to 10 cm (Figure 3c) resulted in the BD increase from 3.79 to 5.66%, depending on the rotor rotation direction. The value k was measured at different depths and considerably high differences were determined at different rotor rotation directions (Figure 3d). With conventional rotary tiller 72.49% higher value was obtained in the lower layer in comparison to the upper soil layer. With reverse rotor rotation direction those differences were not so significant (18.35%). In the case of reverse rotor rotation direction better soil structure was observed with the depth change.
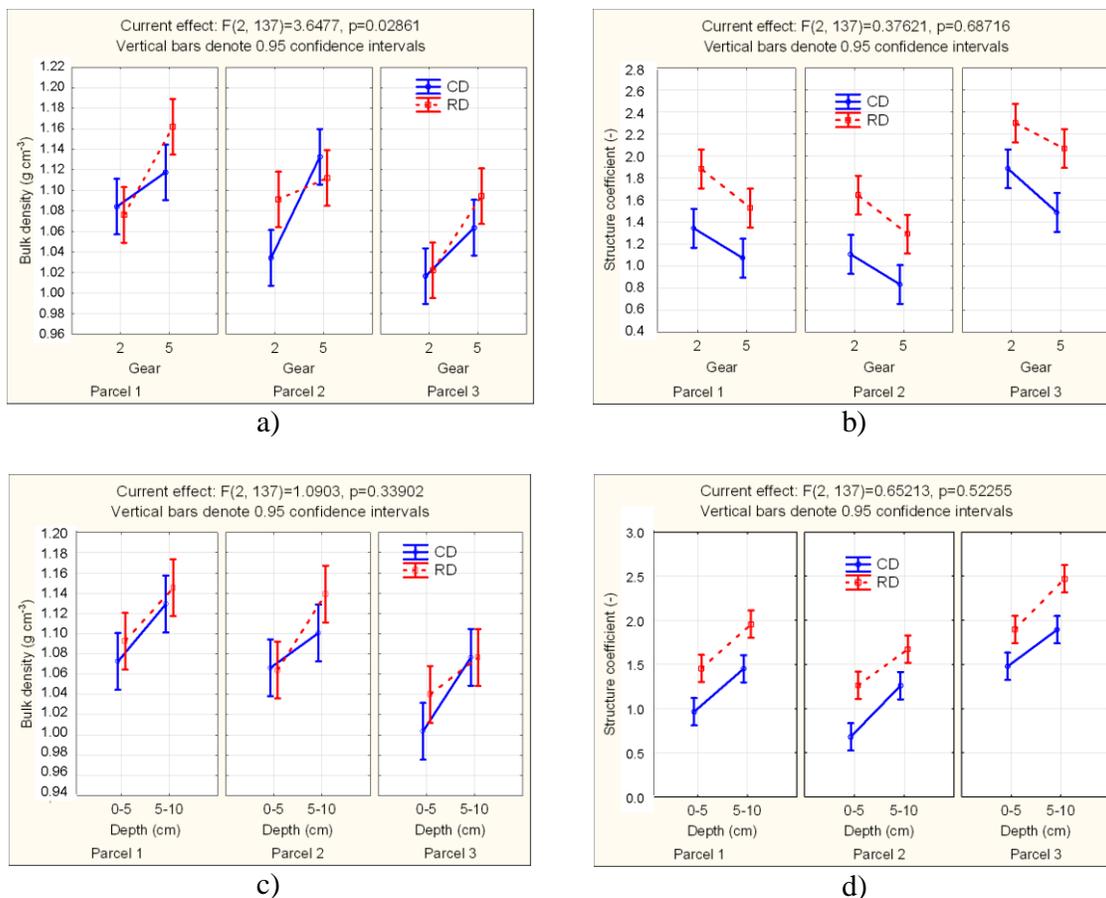
Figure 3. Effects of working parameters on soil physical properties:a, c)-bulk density BD; b, d)-structure coefficient k.

In order to clarify entirely the influence of rotor rotation direction, besides the tillage quality, specific work requirement (SW_{PTO}) and fuel consumption (Q_{PTO}) should also be included.

Specific work requirement during the tillage

In case of conventional rotary tiller, the working speed was up to 4% higher compared to the speed of rotary tiller with the reverse rotor rotation direction. The reason for this was the slippage of wheels that occurred with reverse rotor rotation direction. Tillage depth was measured with respect to the rotor rotation direction, working speed and soil conditions prior to tillage. With the reverse rotation, the depths were 6.23, 8.88 and 1.56% higher for the parcels 1, 2 and 3 respectively, in comparison to the conventional rotary tiller.

Specific work during the tillage was estimated by measuring the PTO power according to Salokhe and Ramalingam (2003). For reverse rotor rotation direction significantly lower values of SW_{PTO} were calculated for Parcel 1 for the first gear, as well as for the Parcel 2 for

the second, third and forth gear (Table 2). On the other hand, no significant differences in the SW_{PTO} were observed for the Parcel 3 (ploughed filed). The highest differences in SW_{PTO} were calculated for Parcel 2 (27.74%) with the most unfavorable soil conditions, then for Parcel 1 (9.37%), and Parcel 3 (-2.15%) had the best least soil conditions. With regard to the conventional rotary tiller the specific work requirement was (on average) 186 kJ m^{-3} and it was for 14.35% higher when compared to the reverse rotor rotation concept where specific work requirement was 160 kJ m^{-3}.

In the case of conventional rotary tiller, fuel consumption (Q_{PTO}) was 5.58 l h^{-1} while for the reverse rotor rotation concept this value was 5.30 l h^{-1} (Table 2). For the conventional rotary tiller, significantly higher fuel consumption was measured for the second and third gear. Based on the measured Q_{PTO} for Parcel 1 (stubble field) the dependence was similar as the one obtained with the specific work requirement (SW_{PTO}).

It is already known that the increase of the working speed leads to the lower values of SW_{PTO} of rotary tiller due to the less intensive soil breaking (Matjašin et al., 1988). Determination coefficient (R^2) for the specific work

Table 2. Specific work requirement (SW$_{PTO}$) and fuel consumption (Q$_{PTO}$) in relation to the rotor rotation direction, gear and soil conditions *.

Direction of rotor rotation	Gear	SW$_{PTO}$ (kJ m^{-3})				Q$_{PTO}$ (l h^{-1})
		Parcel 1	Parcel 2	Parcel 3	Total	Parcel 1
CD	1	305^a	-	-	-	4.94^c
	2	231^{bc}	345^a	113^{ab}	230^a	5.40^b
	3	215^{cd}	288^b	109^{ab}	204^{ab}	5.95^a
	4	188^e	239^c	98^{bc}	175^{bc}	6.00^a
	5	153^f	172de	86^c	137^c	-
	Average	219^A	261^A	101^A	186^A	5.58^A
RD	1	239^b	-	-	-	4.54^c
	2	215^{cd}	208^{cd}	117^a	180^{bc}	4.93^c
	3	195de	198^{cde}	111^{ab}	168^{bc}	5.47^b
	4	180^e	186de	100^{bc}	155^c	6.28^a
	5	158^f	162^e	87^c	135^c	-
	Average	197^A	188^B	104^A	160^B	5.30^A
Index3 = (CD-RD)/CD·100 (%)		9.73	27.74	-2.15	14.35	5.02

*Duncan`s test by columns with the 5% significance threshold.
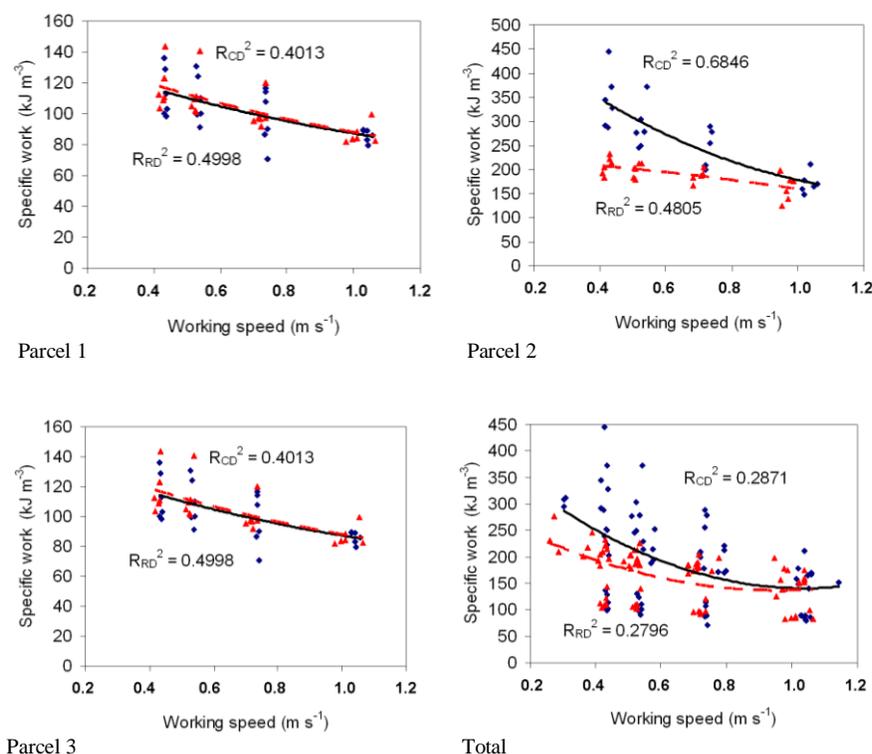

Parcel 1

Parcel 2

Parcel 3

Total

Figure 4. Specific work requirement during tillage (SW$_{PTO}$) in relation to the working speed and rotor rotation direction.

requirement in relation to the working speed for both rotor rotation directions was determined according to the Nonlinear regression (Figure 4). In case of conventional rotor rotation direction (0.85, 0.68 and 0.40) and reverse rotor rotation direction (0.73, 0.48 and 0.50) the obtained values of R^2 were low. The reason for this could be found in non-homogenous soil conditions prior to the tillage.

Testing of the SW$_{PTO}$ with respect to the working speed

Table 3. Intensity of soil breaking*.

Direction	Gear	Ratio of bulk density, x_2 (-)				Ratio of structure coefficient, x_3 (-)			
		Parcel 1	Parcel 2	Parcel 3	Total	Parcel 1	Parcel 2	Parcel 3	Total
CD	2	0.83^a	0.76^c	0.88^a	0.82^b	1.44^{ab}	1.85^b	1.58^b	1.65^{bc}
	5	0.90^a	0.85^a	0.90^a	0.88^{ab}	1.08^b	1.26^b	1.65^b	1.31^c
	Average				0.85^A				1.48^B
RD	2	0.82^a	0.83^{ab}	0.90a	0.85^a	2.16^a	3.07^a	1.91^a	2.39^a
	5	0.91^a	0.82^b	0.91a	0.88^a	1.64^{ab}	2.10^{ab}	1.94^a	1.89^b
	Average				0.87^A				2.14^A
Average		0.87	0.81	0.90	0.86	1.58	2.07	1.77	1.81

*Duncan`s test by columns with the 5% significance threshold.

Table 4. Specific work requirement (SW_{PTO}) in relation to velocity ratio, intensity of soil breaking, soil condition and rotor rotation direction.

Parameter		Parcel 1		Parcel 2		Parcel 3		Total	
		$r_{y,xn}$	$p_{y,xn}$	$r_{y,xn}$	$p_{y,xn}$	$r_{y,xn}$	$p_{y,xn}$	$r_{y,xn}$	$p_{y,xn}$
CD	x_1	**0.94***	**0.81***	**0.90***	**0.65***	**0.80***	**0.67***	**0.53***	**0.28***
	x_2	**-0.71***	0.09	**-0.88***	-0.01	**-0.62***	-0.15	**-0.69***	**-0.48***
	x_3	**0.65***	**0.49***	**0.79***	**0.48***	**0.63***	**0.35***	**0.40***	0.11
	x_4	0.17	-0.09	-0.01	0.09	-0.33	-0.21	0.32	**0.30***
RD	x_1	**0.91***	**0.76***	**0.72***	**0.47***	**0.81***	**0.81***	**0.49***	**0.32***
	x_2	**-0.76***	-0.03	0.09	-0.16	-0.32	0.10	**-0.59***	-0.21
	x_3	**0.60***	0.40	**0.87***	**0.67***	0.43	**0.43***	**0.52***	**0.33***
	x_4	0.18	-0.11	-0.20	-0.17	-0.18	-0.15	**0.58***	**0.52***

*Bolded values were statistically significant at 5% significance threshold.

resulted in the equations with low R^2 values for all three parcels (Total, Figure 4), and those values were 0.29 and 0.28 for conventional and reverse rotation direction, respectively. In this study, more accurate determination of SW_{PTO} in the working conditions was obtained by considering not only the working speed, but also the soil conditions prior the tillage and the tillage quality.

Correlation and Path analyses of the parameters that influence the rotary tiller SW_{PTO}

During the testing, the rotor speed of rotary tiller had constant value of 153 min^{-1}. Working speed and velocity ratio (x_1) are in the reverse proportional dependence for equal rotor speed (Equation 3).

Soil conditions prior to tillage and tillage quality were determined based on the intensity of soil breaking parameters (ratio of bulk density x_2 and ratio of structure coefficient x_3). The values of intensity of soil breaking parameters were calculated by Equations (4) and (5).

Lower value of x_2 and higher value of x_3 imply better intensity of soil breaking (Table 3).

Statistically significant differences in the intensity of soil breaking parameters (x_2 and x_3) were not observed after the shift to a higher gear. The change in the rotor rotation direction showed statistically equal values of x_2, but considerably higher values of x_3 for the reverse rotor rotation direction (Table 3).

The influences of velocity ratio (x_1), intensity of soil breaking (x_2 and x_3) and soil conditions (x_4) on rotary tiller specific work requirement were determined by testing the simple correlation coefficients ($r_{y,xn}$) and Path coefficients ($p_{y,xn}$). The testing was carried out for each parcel individually and in total for all three parcels (Table 4).

Comparing SW_{PTO} and velocity ratio (x_1), positive and statistically significant correlation was obtained for every tested parcel and both directions of rotor rotation (Table 4). For the conventional rotary tiller correlation coefficients were in the range from $r_{y,x1} = 0.80$-0.94 while Path coefficients were $p_{y,x1} = 0.65$-0.81. In the case of reverse rotor rotation these values were $r_{y,x1} = 0.72$-0.91

and $p_{y,x1}$ = 0.47-0.81. It can be concluded that the velocity ratio influences greatly the SW_{PTO}. Higher x_1 implies higher SW_{PTO}, too (Asl and Singh, 2009).

For the simple correlation coefficient, statistically significant values were determined as well as negative influence of bulk density ratio (x_2) on the SW_{PTO}. These values were in the range from $r_{y,x2}$ = 0.62-0.88 for the conventional rotary tiller and $r_{y,x2}$ = 0.09-0.76 for reverse rotor rotation direction. However, applying the Path coefficient analysis, the values were not significant for the bulk density ratio (x_2) which implied the existence of strong indirect influence of bulk density ratio (x_2) on the structure coefficient ratio (x_3) and velocity ratio (x_1). High and negative simple correlation coefficient between bulk density ratio (x_2) and SW_{PTO} was observed for the conventional rotor rotation direction, however, lower value was observed for the reverse rotor rotation. Weber and Biskupski (2008) have also found negative coefficient of simple regression for the bulk density. Bulk density ratio (x_2) is very suitable for precise quality analysis prior to and after the tillage.

Structure coefficient ratio (x_3) had positive influence on the SW_{PTO}. Statistically significant values of simple correlation coefficient were determined and they were in the range from $r_{y,x3}$ = 0.63-0.79 for the conventional rotary tiller and $r_{y,x3}$ = 0.43-0.87 for the rotary tiller with reverse rotor rotation direction. The analyses of Path coefficients showed statistically significant values for both conventional and reverse rotation rotary tiller (Parcels 2 and 3). The values were $p_{y,x3}$ = 0.35-0.49 for conventional and $p_{y,x3}$ = 0.40-0.67 for reverse rotation concept. High values for the tested coefficients show high dependence between SW_{PTO} and structure coefficient ratio (x_3). Structure coefficient ratio (x_3) is very suitable for more precise analysis regarding the working regime (Factor 1 and 2). Moisture content (x_4) was determined only prior to tillage and it represented the soil condition. As it was expected (constant value for every Parcel), there were no significant values for the simple correlation and Path coefficients. The analyses for all three parcels together (Total, Table 3) were also conducted. In case of conventional rotary tiller statistically significant values for the simple correlation coefficient were determined ($r_{y,x1}$ = 0.52; $r_{y,x2}$ = -0.69 and $r_{y,x3}$ = 0.40). The highest and negative correlation ($r_{y,x2}$) was determined between SW_{PTO} and the bulk density ratio (x_2). Statistically significant values were also determined for Path coefficient ($p_{y,x1}$ = 0.26; $p_{y,x2}$ = -0.49 and $p_{y,x4}$ = 0.30). The bulk density ratio (x_2) had the most important direct negative influence ($p_{y,x2}$) on SW_{PTO}. Path coefficient ($p_{y,x3}$) for structure coefficient ratio (x_3) was not significant. The influence of structure coefficient ratio (x_3) could be seen through the indirect regression coefficients $r_{x3,x1}{}^*p_{y,x2}$ = 0.10 via (x_1); $r_{x3,x2}{}^*p_{y,x2}$ = 0.26 via (x_2) and $r_{x3,x4}{}^*p_{y,x4}$ = 0.07 via (x_4). The structure coefficient ratio (x_3) had the highest statistical indirect influence on the bulk density ratio (x_2).

For the rotary tiller with reverse rotor rotation direction, the values of simple correlation coefficients were statistically significant for all four independent variables. The values were $r_{y,x1}$ = 0.48; $r_{y,x2}$ = -0.59; $r_{y,x3}$ = 0.52 and $r_{y,x4}$ = 0.58, respectively. The highest value of simple correlation coefficient was found for the bulk density ratio (x_2). When direct Path coefficients were analyzed, they showed statistically significant value for three independent variables. The obtained values were $p_{y,x1}$ = 0.32; $p_{y,x3}$ = 0.33 and $p_{y,x4}$ = 0.52. The independent variable (x_2) was not significant and its influence could be seen through indirect Path coefficients $r_{x2,x1}{}^*p_{y,x1}$ = -0.09 via (x_1); $r_{x2,x3}{}^*p_{y,x3}$ = -0.17 via (x_3) and $r_{x2,x4}{}^*p_{y,x4}$ = -0.13 via (x_4). The independent variable (x_2) had the most intensive indirect influence on the independent variable (x_3). Based on the calculated Path coefficients, the highest influence on the SW_{PTO} had the structure coefficient ratio (x_3) and soil moisture content (x_4).

The soil moisture content (x_4) and SW_{PTO} showed positive correlation, too. The testing was performed under the optimal values of soil moisture when minimal SW_{PTO} was applied (Birkás, 2008).

Since statistically significant correlation was determined between the dependent variable (SW_{PTO}) and the observed independent variables (x_1, x_2, x_3 and x_4), Multiple linear regression was used to determine their interdependence (mathematical equation).

Multiple linear regression on rotary tiller SW_{PTO}

Multiple linear regression was used for determining the mathematical dependence (Equations 6-13) between the independent (x_1; x_2; x_3 and x_4) and dependent variable (y = SW_{PTO}) with respect to the parcel and direction of rotor rotation:

$$SW_{PTO(Parcel\ 1CD)} = 122.0 + 12.2 \cdot x_1 + 50.4 \cdot x_2 + 42.1 \cdot x_3 - 4.6 \cdot x_4$$
$$(R^2 = 0.99;\ Se = 5.35) \tag{6}$$

$$SW_{PTO(Parcel\ 1RD)} = 205.1 + 7.7 \cdot x_1 - 13.3 \cdot x_2 + 16.7 \cdot x_3 - 4.0 \cdot x_4$$
$$(R^2 = 0.93;\ Se = 10.55) \tag{7}$$

$$SW_{PTO(Parcel\ 2CD)} = -180.1 + 22.4 \cdot x_1 - 17.2 \cdot x_2 + 79.0 \cdot x_3 + 8.8 \cdot x_4$$
$$(R^2 = 0.97;\ Se = 22.64) \tag{8}$$

$$SW_{PTO(Parcel\ 2RD)} = 405.5 + 5.5 \cdot x_1 - 239.3 \cdot x_2 + 19.0 \cdot x_3 - 5.4 \cdot x_4$$
$$(R^2 = 0.94;\ Se = 10.00) \tag{9}$$

$$SW_{PTO(Parcel\ 3CD)} = 157.8 + 4.3 \cdot x_1 - 45.0 \cdot x_2 + 43.3 \cdot x_3 - 6.1 \cdot x_4$$
$$(R^2 = 0.92;\ Se = 6.49) \tag{10}$$

$$SW_{PTO(Parcel\ 3RD)} = 44.5 + 5.4 \cdot x_1 + 36.6 \cdot x_2 + 39.7 \cdot x_3 - 4.7 \cdot x_4$$
$$(R^2 = 0.84;\ Se = 9.63) \tag{11}$$

$$SW_{PTO(CD)} = 298.1 + 9.1 \cdot x_1 - 598.5 \cdot x_2 + 21.1 \cdot x_3 + 14.6 \cdot x_4$$
$$(R^2 = 0.62;\ Se = 59.12) \tag{12}$$

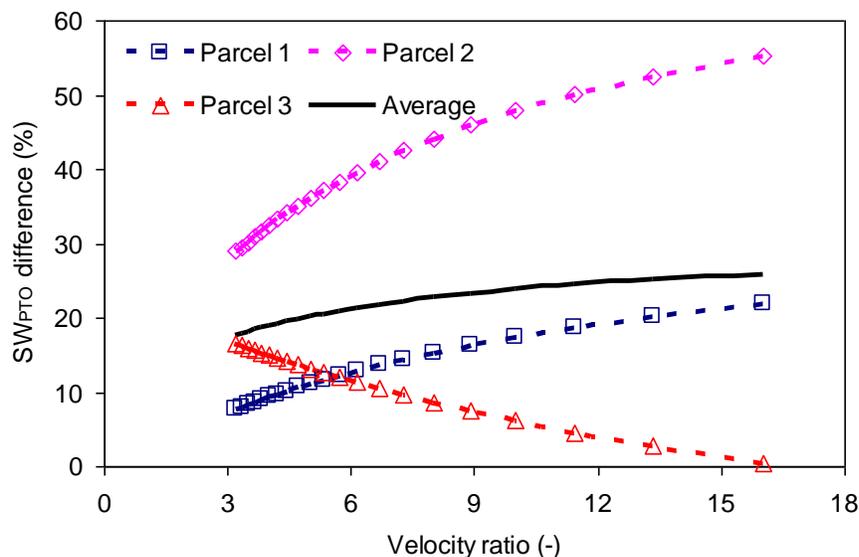**Figure 5.** SW_{PTO} difference due to the change in the rotor rotation direction.

$SW_{PTO(RD)}$ = -70.9+5.4·x_1-152.4·x_2+18.9·x_3+13.6·x_4
(R^2 = 0.75; Se = 26.05) (13)

Values for the determination coefficient (R^2) were very high in both cases (conventional and reverse concept). For Parcels 1, 2 and 3 the values were 0.99, 0.97 and 0.92, respectively, for conventional rotary tiller and 0.93, 0.94 and 0.84 for the rotary tiller with reverse rotor rotation direction. The standard error (Se) was 5.35-22.64 kJ m^{-3}. Using the data obtained from all parcels, determination coefficients (R^2) were lower values because of the different conditions of the tested parcels (Equation 12 and 13). The R^2 values were 0.62 for the conventional rotary tiller and 0.75 for the tiller with the reverse rotor rotation direction.

Specific work requirement differences regarding the rotor rotation direction

For given values of intensity of soil breaking (x_2 and x_3) (average values, Table 3) and soil moisture (x_4), the SW_{PTO} values were calculated (Equations 6-13) depending on the working regime (velocity ratio, x_1) for both rotor rotation directions. The SW_{PTO} values were higher for the conventional rotor rotation direction. After that, the differences in SW_{PTO}, which occurred as a result of the change in rotor rotation direction, were calculated (Figure 5).

By increasing the velocity ratio (x_1), SW_{PTO} difference, which occurred due to the change in the rotation direction (Figure 5), showed a tendency of increase for Parcels 1 and 2, and a tendency of slight decrease for the Parcel 3. The working speed was calculated for the given rotor speed and radius by applying the Equation (3) for the

velocity ratio (x_1). The SW_{PTO} calculated values were lower for the reverse rotor rotation. Depending on the parcel, the SW_{PTO} difference ranged from 8.6-44.2% (20.3% on average) for the working speed of 0.5 m s^{-1}, while for the working speed of 1.0 m s^{-1} this difference ranged from 9.4-32.4%, (15.5% on average). By increasing the working speed, the SW_{PTO} difference decreased due to the change in the rotation direction.

DISCUSSION

The analysis of tillage quality, with respect to different depths, gave 72.49% higher values of the structure coefficient (k) for the conventional rotor rotation direction, while in the case of the reverse rotor rotation the values were only 18.35% higher (Figure 3). The conventional rotary tiller caused unnecessary intensive tillage in the deeper soil layers (5 to 10 cm). The elimination of unnecessary soil breakup will lead to the energy saving (Matjašin et al., 1988) and preservation of the soil resources with lower CO_2 release (Lal, 2000). With respect to the tillage quality, the following requirements should be met in the production of root vegetables (Bajkin et al., 2010): the upper soil layer should be crushed enough, while the presence of mega-structure aggregates should increase with deeper soil layers which would provide more favorable water, air and heat regimes of the soil. Birkás (2008) stated that, in order to have a good seed bed preparation, the ratio of micro-structure aggregates must be 70 to 80%. Hakansson et al. (2002) stated that the share of aggregates larger than 5 mm in diameter should be below 50% in order to have a good tillage quality.

After conducting an extensive research in the field conditions (Table 1), it was concluded that the reverse rotor rotation direction provided better tillage quality (visible even without the measuring) which was in accordance with the research results obtained in the laboratory (Lee et al., 2003) and field conditions (Salokhe and Ramalingan, 2001). Statistically significant differences (38.76%) were determined by measuring the structure coefficient (k), while the results obtained by measuring the BD did not show any significant differences (1.87%). This research implies that the soil structure analysis is necessary in order to determine the tillage quality with different working parameters (working speed, rotor rotation direction). Based on the tillage quality analysis the obtained results were used as a basis for determining the differences in SW_{PTO} depending on rotary tiller rotor rotation direction.

The increase of working speed led to lower SW_{PTO} for all soil conditions, which was already known (Matjašin et al., 1988; Salokhe and Ramalingam, 2003; Kheiralla et al., 2004; Asl and Singh, 2009). The analysis of the influence of rotor rotation direction on the SW_{PTO} showed significantly lower values (14.35% on average, Table 2) for the reverse rotor rotation direction. The measuring of the SW_{PTO} and working speed in the field conditions showed relatively low values of the determination coefficient (R^2) which, depending on the tested parcel, ranged from 0.40-0.85 (Total 0.29) for the conventional and 0.50 to 0.73 (Total 0.28) for the reverse rotor rotation. Testing the blade's shape in the laboratory conditions, Asl and Singh (2009) determined the linear dependence between SW_{PTO} and velocity ratio with $R^2 = 0.85-0.88$. Applying the same methodology in this research, lower R^2 values were obtained for the testing performed in the field conditions, which was the result of varied soil conditions. With the aim of precise determination of SW_{PTO} values (higher R^2 values), besides the working regime parameters, tillage quality and soil condition parameters were included in the analysis, too. Simple correlation and standard regression coefficients, i.e. Path analysis (Table 4), showed high and statistically significant correlation between SW_{PTO} and following independent variables (velocity ratio x_1, ratio of bulk density x_2, ratio of structure coefficient x_3 and soil moisture x_4).

By using the Multiple linear regression the equations (6 to 11) were obtained for the determination of SW_{PTO} with high values of R^2, within the limits of 0.92-0.99 for conventional, and within the limits of 0.84-0.94 for the reverse rotor rotation direction. Thus, more accurate results were obtained in comparison to the mentioned equations for SW_{PTO} in the laboratory conditions (Asl and Singh, 2009). The analysis of working parameters, intensity of soil breaking and soil conditions gave precise evaluation of SW_{PTO}.

Since the change in the rotor rotation direction results in different tillage quality and SW_{PTO}, the final evaluation

of SW_{PTO} differences was performed by using the equations (6 to 11). The SW_{PTO} values were calculated for the same and already given values of the tillage intensity (Average values of x_2 and x_3; Table 3) and soil moisture (x_4). The obtained values for SW_{PTO} were lower for the reverse rotation direction. The differences in SW_{PTO} values (Figure 5) were, depending on the parcel, within the range of 8.6 to 44.2% (20.3% on average) for the working speed of 0.5 m s^{-1}, and 9.4 to 32.4%, (15.5% on average) for the working speed of 1.0 m s^{-1}. Higher SW_{PTO} differences were determined for lower values of the working speed (higher values of the velocity ratio x_1) and more unfavorable soil conditions (Parcels 1 and 2).

This research has undoubtedly presented the advantages of reverse rotor rotation direction which provides less SW_{PTO} for the same intensity of soil breaking and better arrangement of soil aggregates per soil depth. The advantages are even more obvious with lower working speed and unfavorable soil tillage conditions. Also, it can be concluded that the rotary tiller with reverse rotation concept should be used as a part of a complex soil preparation machine (Ponjican, 2009) in conditions of lower speed regimes, higher values of bulk density and on soils covered with plant residues.

ACKNOWLEDGEMENT

REFERENCES

Asl JH, Singh S (2009). Optimization and evaluation of rotary tiller blades: Computer solution of mathematical relations. Soil Till. Res., 106: 1-7.

Bajkin A, Ponjičan O, Zoranović M (2010). The impact of tillage on physical features and carrot root yield. J. Process. Energy Agric., 14: 169-172.

Balesdent J, Chenu C, Balabane M (2000). Relationship of soil organic matter dynamics to physical protection and tillage. Soil Till. Res., 53: 215-230.

Birkás M (2008). Environmentally-sound adaptable tillage, Akadémiai Kiadó, p. 351.

Celik A, Altikat S (2008). Geometrical Analysis of the Effect of Rotary Tiller Blade Path on the Distribution of Soil Slice Size: Technical Note. Appl. Eng. Agric., 24: 409-413.

Djurovka M (2008). Vegetable growing in open field (Gajenje povrća na otvorenom polju in Serbian), Faculty of Agriculture, Novi Sad, Serbia, p. 251.

Hakansson I, Myrbeck A, Etana A (2002). A review of research on seedbed preparation for small grains in Sweden. Soil Till. Res., 64: 23-40.

Horn R (1990). Aggregate characterization as compared to soil bulk properties. Soil Till. Res., 17: 265-289.

Kataoka T, Sibusawa S (2002). Soil-blade dynamics in reverse-rotational rotary tillage. J. Terramech., 39: 95-113.

Kosutic S, Filipovic D, Gospodaric Z (1997). Agrotechnical and energetic characteristics of a rotary cultivator with spike tines in seedbed preparation. Int. Agric. Eng. J., 6: 137-144.

Keller T, Arvidsson J, Dexter B (2007). Soil structures produced by tillage as affected by soil water content and the physical quality of soil. Soil Till. Res., 92: 45-52.

Kheiralla F, Yahya A, Zohadie M, Ishak W (2004). Modeling of power and energy requirements for tillage implements operating in Serdang sandy clay loam, Malaysia. Soil Till. Res., 78: 21-34.

Lal R (2000). Soil management in developing countries. Soil Sci., 165: 57-72.

Lazić B, Djurovka M, Marković V, Ilin Ž (2001). Vegetable (Povrtarstvo, in Serbian). University of Novi Sad, Faculty of Agriculture, Novi Sad, Serbia, p. 472.

Li CC (1975). Path Analysis – a primer. Pacific Grove, California, USA.

Lee KS, Park SH, Park WY, Lee CS (2003). Strip tillage characteristic of rotary tiller blades for use in a dry land direct rice seeder. Soil Till. Res., 71: 25-32.

Matjašin JI, Grincuk IM, Egorov GM (1988). Outlay and plan rotary machines. (Расчет и проектипование ротационных машин. In Russian), Agropromizdat, Moscow, Russia.

Petrovic DV, Mileusnic ZI, Miodragovic RM (2010). Correlations between statistical moments of soil aggregate size distributions. Int. Agrophys., 24: 287-296.

Ponjican O, Bajkin A, Nesic Lj (2008). Effects of differently constructed machines for the bed preparation on soil structure in the carrot production. J. Process. Energy Agric., 12(3): 164-167.

Ponjican O (2009). Analysis of parameters of mini-bed forming machine for production of root vegetables (in Serbian). Ph.D. Thesis, Faculty of agriculture, University of Novi Sad, Serbia.

Ponjican O, Bajkin A, Matic-Kekic S, Dedovic N (2011). Influence of the rotary tiller construction on tillage quality and soil degradation. 22nd International symposium: Safe food production. Trebinje, Bosnia and Herzegovina, Proceedings, pp. 449-451.

Páltik J, Findura P, Polc M (2003). Machines for plant production, soil tillage, seeding. (Stroje pre rastlinnú výrobu, obrábanie pôdy, sejba. In Slovakian). Slovak University of Agriculture in Nitra, Slovakia.

Rubatzky VE, Quiros CF, Simon PW (1999). Carrots and related vegetable, Umbelliferae. CABI Publ. New York.

Sakin E, Deliboran A, Tutar E (2011). Bulk density of Harran plain soils in relation to other soil properties. Afr. J. Agric. Res., 6(7): 1750-1757.

Salokhe VM, Ramalingam N (2001). Effect of direction of rotation of a rotary tiller on propertis of Bankok clay soil. Soil Till. Res., 63: 65-74.

Salokhe M, Ramalingan N (2003). Effect of rotation direction of rotary tiller on draft and power requirements in a Bangkok clay soil. J. Terramech., 39: 195-205.

Saimbhi VS, Wadhwa DS, Grewal PS (2004). Development of rotary tiller blade using three-dimensional computer graphic. Biosyst. Eng., 89: 47-58.

Sümer SK, Kocabıyık H, Say SM, Çiçek G (2010). Fuel consumption distribution for machine and tractor activities in some PTO driven machine operations. Afr. J. Agric. Res., 5(9): 824-828.

Šein B, Arhangelskaja A, Goncarov M, Guber K, Pocatkova N, Siborova A. Umbarova B (2001). Field and laboratory methods appreciation physical properties and conditions of soil. (Полевые и лабораторные методы исследования физических свойстед и режимоб почв. In Russian). University in Moscow, Moscow, Russia.

Van Dang M (2007). Quantitative and qualitative soil quality assessments of tea enterprises in Northern Vietnam. Afr. J. Agric. Res., 2(9): 455-462.

Weber R, Biskupski A (2008). Effect of penetration resistance, bulk density and moisture content of soil on selected yield components of winter triticale in relation to method of cultivation. Int. Agrophys., 22: 171-177.

ISO 10381-6.ISO/IEC 17025.