# Kinematics of twin rotary tiller

M. Belov

(*Department of Machine Parts, Faculty of Technical Service in the Agro-Industrial Complex, Russian State Agrarian University − Moscow Agricultural Academy by K. A. Timiryazev, 127550, Timiryazevskaya Ulitsa, 49, Moscow, Russia*)

**Abstract:** Kinematics of twin rotary tiller with a big front rotor was investigated. This tiller contains two rotors with horizontal axes one behind another. The twin rotary tiller with L-shaped blades can be used for heavy loamy soil handle. The rear rotor is designed to handle upper soil layer. Theoretical methods and computer model were used to calculate the radius of the rear rotor, the position of the rotor above land surface, rotational rotor speed, tractor forward speed at desired sizes of slice pierce in the upper layer of soil and at given number of blades on one side of a flange. The investigation showed that one rotor rotary tiller did not provide equal sizes of an upper pierce of a slice, when ratio of distance between the horizontal axis of the rotor and initial soil surface to the tilling depth was equal to 1/4. Twin rotary tillers could provide equal sizes of pierce of a slice in the upper layer of soil. Under tilling depth 200 mm, the height and width of the pierce could be equal to 40 mm or less.

**Keywords:** kinematics of rotary tiller, kinematics of twin rotary tiller

**Citation:** Belov, M. 2018. Kinematics of twin rotary tiller. Agricultural Engineering International: CIGR Journal, 20(4): 91–96.

## 1 Introduction

The methods of tillage affect soil structure and productivity of plants (Shamsabadi et al., 2017). Rotary tiller treatment provides better quality of soil in comparison with plow treatment (Zhang et al., 2018). A rotary tiller soil treatment permits to save 30%-35% time and 20%-25% cost of operation as compared to tillage by cultivator (Shinde and Kajale, 2012). Sizes of soil pierces can be considered as main indicators of soil treatment quality. The point of a rotary tiller blade traces a trochoidal trajectory in the soil. A slice of soil between adjacent trajectories in the vertical longitudinal plane is divided into parts by the next trajectories. The volume of each soil slice, the volume of each part of the slice and the number of cuts of a slice by a blade depend on the number of blades on one side of a flange, rotor radius, tractor forward speed and rotor rotational speed (Celik and Altikat, 2008). The L-shaped blade with small cross-sectional area is suited well to cut soil slices. The kinematic parameter (λ-ratio or ratio of a blade end point speed to tractor forward speed) affects size of soil aggregate (Dhruwe et al., 2018). The better treatment of heavy loamy soil can be provided by multiple cuts. Under typical rotary tiller dimensions and operating conditions, the pierces in the upper layer of soil are enough large and larger than the pierces in the lower layer. The twin rotary tiller enables to decrease sizes of soil pierces in the upper soil layer.

The twin rotary tiller with L-shaped blades is considered (Figure 1). Such a tiller contains two rotors with horizontal parallel axes of rotation one behind another. The rotors rotate in conventional direction. The (maximal) depth of tillage is provided with the blades of the front rotor. The blades of the rear rotor handle the upper lay of soil. The front rotor provides rough handle of soil, and the rear rotor is designed to handle the upper layer into pieces of approximately equal desired sizes.

Tilling depth is a sum of minimal tilling depth and ridge height (Celik et al., 2008).

The purpose of this study was to calculate the radius

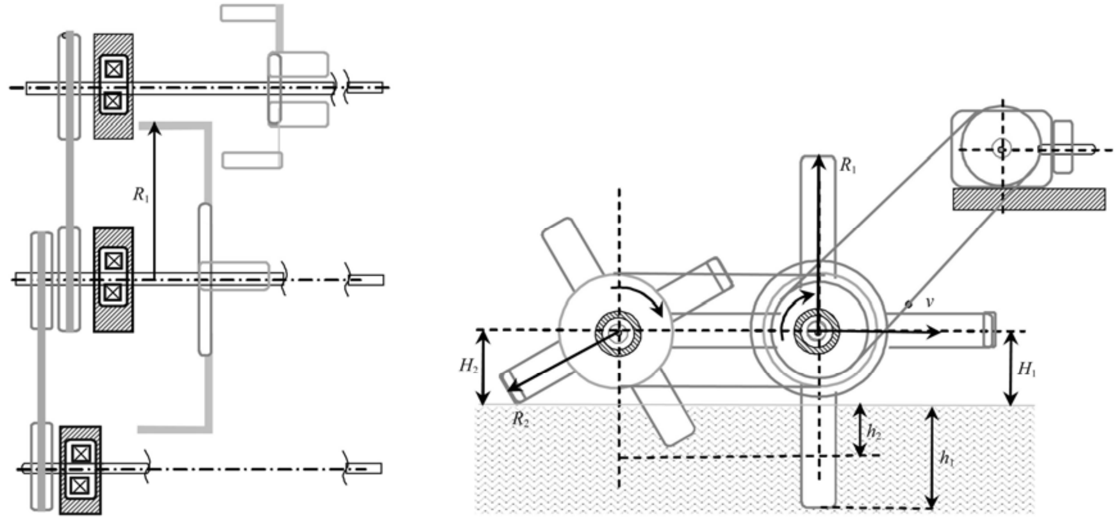
**Received date:** 2017-12-12 **Accepted date:** 2018-02-13

***Corresponding author: Belov, M.,** Department of Machine Parts, Faculty of Technical Service in the Agro-Industrial Complex, Russian State Agrarian University − Moscow Agricultural Academy by K. A. Timiryazev. Email: B-Mikhael@yandex.ru.

of the rear rotor, position of the rotor above surface of land, the minimal depth of tillage, rotational speed, tractor forward speed at desired size of soil pierce in the upper layer of soil and at given number of blades on one side of a flange.

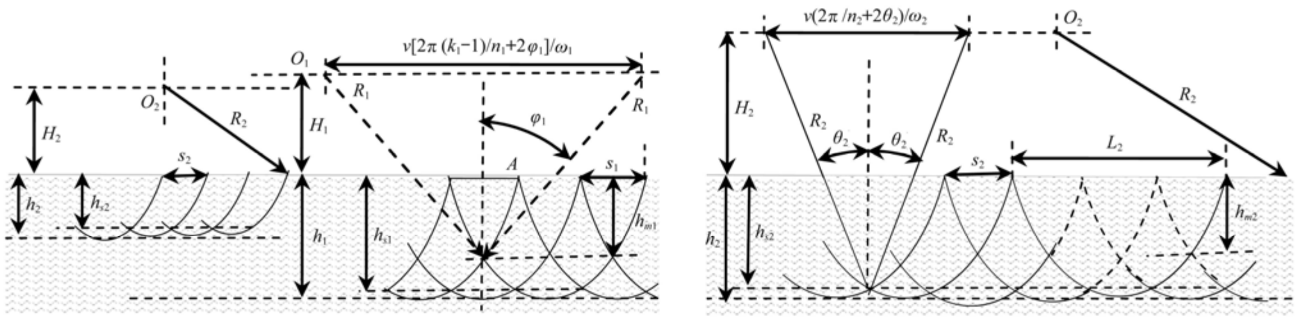
## 2 Theory and methods

### 2.1 Designations (nomenclature) (Figure 1, & 2)




a. Top view b. Side view

Figure 1 Twin rotary tiller




a. The upper layer and the bottom b. The upper layer

Figure 2 The trajectories of tips of the blades ($k_1$=$k_2$=3)

Note: $n_1$ – a number of blades on one side of a flange on the front rotor; $n_2$ – a number of blades on one side of a flange on the rear rotor; $R_1$ – the radius of the front rotor, m; $R_2$ – the radius of the rear rotor , m; $H_1$ – distance between the horizontal axis of the front rotor and initial soil surface, m; $H_2$ – distance between the horizontal axis of the rear rotor and initial soil surface, m; $h_1$ – the tilling depth for the front rotor, m; $h_2$ – the tilling depth for the rear rotor, m; $h_{s1}$ – the minimal tilling depth at the front rotor, m; $h_{s2}$ – the minimal tilling depth at the rear rotor, m; $h_{m1}$ – the height of the high pierce of a slice at the front rotor, m; $h_{m2}$ – the height of the high pierce of a slice at the rear rotor, m; $s_1$ – the tillage pitch at the front rotor, m; $s_2$ – the tillage pitch at the rear rotor, m; $k_1$ – a number of cuts of a slice by the blades of the front rotor ($k_1 \geq 2$) ; $k_2$ – a number of cuts of a slice by the blades of the rear rotor ($k_2 \geq 2$) ; $L_1$ – distance between the points of a blade of the front rotor in the moments of entry into the soil and exit from the soil in the vertical longitudinal plane, m; $L_2$ – distance between the points of a blade of the rea rotor in the moments of entry into the soil and exit from the soil in the vertical longitudinal plane, m; $2\theta_1$ – the angle of rotation of the front rotor for the time between the moments when tips of successive blades reach the minimal tilling depth, rad ($\pi>2\theta_1>0$); $2\theta_2$ – the angle of rotation of the rear rotor for the time between the moments when tips of successive blades reach the minimal tilling depth, rad ($\pi > 2\theta_2 > 0$); $\omega_1$ – the angular velocity of the front rotor, rad $s^{-1}$; $\omega_2$ – the angular velocity of the rear rotor, rad $s^{-1}$; $v$ – the forward speed of a tractor, m $s^{-1}$.

### 2.2 Basic variables and equations

The following dimensionless variables are chosen: $n_1$, $k_1$, $(H_1/h_1)$, $(R_1/h_1)$, $(h_{s1}/h_1)$, $(h_{m1}/h_1)$, $(s_1/h_1)$, $(L_1/h_1)$, $\lambda_1$, $\theta_1$, $n_2$, $k_2$, $(R_2/h_2)$, $(H_2/h_2)$, $(h_{s2}/h_2)$, $(h_{m2}/h_2)$, $(s_2/h_2)$, $(L_2/h_2)$, $\lambda_2$, $\theta_2$,

where

$$\lambda_1 = \omega_1 R_1/v,\ \lambda_2 = \omega_2 R_2/v$$

The main relationships between these parameters are known (Hendrick and Gill, 1971a, 1971b, 1971c, 1978). It is convenient to write the equations using dimensionless variables:

$$(H_1/h_1)+1 = (R_1/h_1) \tag{1}$$

$$\lambda_1(s_1/h_1) = (2\pi/n_1)(R_1/h_1) \tag{2}$$

$$(H_1/h_1) + (h_{s1}/h_1) = (R_1/h_1)\cos\theta_1 \tag{3}$$

$$\lambda_1\sin\theta_1 = \pi/n_1 + \theta_1 \tag{4}$$

$$(H_2/h_2) + 1 = (R_2/h_2) \tag{5}$$

$$\lambda_2(s_2/h_2) = (2\pi/n_2)(R_2/h_2) \tag{6}$$

$$(H_2/h_2) + (h_{s2}/h_2) = (R_2/h_2)\cos\theta_2 \tag{7}$$

$$\lambda_2 \sin\theta_2 = \pi/n_2 + \theta_2 \quad (8)$$

### 2.3 The task and additional equations

The front rotor was considered at first. The task was put on to find rotor parameters providing equality between height of upper pierce of a slice and width of upper pierce of a slice. It was suggested that quality of soil cutting was satisfactory if the height and width were equal to 50 mm or less. The tilling depth was assigned equal to 200 mm.

It was accepted that the last cut of a slice 1 took place in a point $A$ (Figure 2a).

Therefore, the following equation was correct:

$$L_1/h_1 = k_1(s_1/h_1) \quad (9)$$

The following formula was used to calculate the value $L_1$:

$$L_1 = 2\sqrt{R_1^2 - H_1^2} - 2(R_1/\lambda_1)\arccos(H_1/R_1)$$

The last equation was recompiled after replacing $L_1/h_1$ by the Equation (9) and using the Equations (1), (2) as follows:

$$k_1(s_1/h_1) = 2\sqrt{1 + 2(H_1/h_1)} - (n_1/\pi)(s_1/h_1) \arccos\{(H_1/h_1)/[(H_1/h_1)+1]\} \quad (10)$$

The Equation (10) enabled to calculate the value of variable $(s_1/h_1)$, if the values of variables $(h_1/h_1)$, $k_1$, $n_1$ were given.

The value $(h_{m1}/h_1)$ depended on the value $k_1$ (Figure 2a). The modified Equations (3), (4) was used to find the value $(h_{m1}/h_1)$ as follows:

$$(H_1/h_1) + (h_{m1}/h_1) = (R_1/h_1)\cos\varphi_1 \quad (11)$$

$$\sin\varphi_1 = [\pi(k_1 - 1)/n_1 + \varphi_1]/\lambda_1 \quad (12)$$

where, $\varphi_1$ – parameter as $\theta_1$ ($\pi/2 > \varphi_1 > 0$).

Equations (1), (4), (9), (12) contained 11 dimensionless variables: $n_1$, $k_1$, $(H_1/h_1)$, $(R_1/h_1)$, $(h_{s1}/h_1)$, $(h_{m1}/h_1)$, $(s_1/h_1)$, $(L_1/h_1)$, $\lambda_1$, $\theta_1$, $\varphi_1$.

So, the values of three independent variables enabled to calculate the values of eight dependent variables.

It was accepted that the rotor moved forward without soil resistance at the moment of blade entry in the soil:

$$H_1\omega_1 > v$$

or, using the Equation (1),

$$\lambda_1 > \lambda_{k1} \quad (13)$$

where, $\lambda_{k1} = 1 + 1/(H_1/h_1)$.

The Euqations (9)... (13) could be used to investigate rear rotor after replacement of front rotor variables by appropriate rear rotor variables: $n_2$, $k_2$, $(H_2h_2)$, $(R_2/h_2)$, $(h_{s2}/h_2)$, $(h_{m2}/h_2)$, $(s_2/h_2)$, $(L_2/h_2)$, $\lambda_2$, $\theta_2$ and $\lambda_{k2}$, where $\lambda_{k2} = 1 + 1(H_2/h_2)$.

### 2.4 Algorithm for calculations

1. The numerical values were assigned for three variables: $n_1$, $k_1$, $(H_1/h_1)$.

Typical rotary tiller dimensions were adopted in selecting the value of variable $(H_1/h_1)$. It was considered that radius of the front rotor was equal to 250 mm and depth of tillage – 200 mm, $n_1$=2,3, $k_1$=2…8. So, $(H_1/h_1)$= 0.25.

2. The value $(R_1/h_1)$ was calculated from the Equation (1).

3. The value $(s_1/h_1)$ was calculated from the Equation (10).

4. The value $\lambda_1$ was calculated from the Equation 2.

5. The inequality 13 was verified.

6. The value $\theta_1$ was calculated from the Equation (4); numerical Newton's method was used (Korn and Korn, 1968).

7. The value $(h_{s1}/h_1)$ was calculated from the Equation 3.

8. The value $\varphi_1$ was calculated from the Equation (12); numerical Newton's method was used.

9. The value $(h_{m1}/h_1)$ was calculated from the Equation (11).

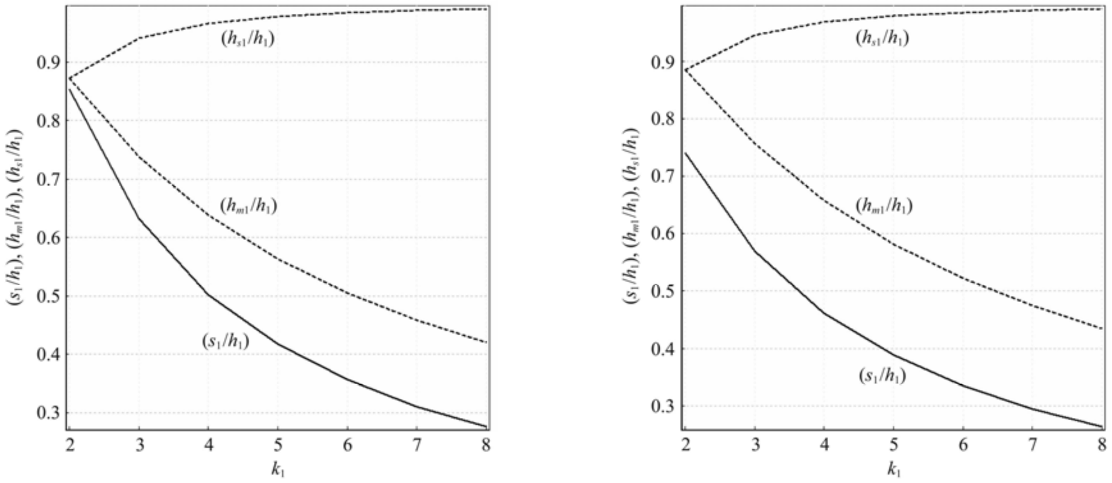
The calculations on items 1−9 are correct for the rear rotor too after replacement of front rotor variables by appropriate rear rotor variables. It was accepted that value $(H_2/h_2)$ was enclosed in the specified bounds: $0.2 < (H_2/h_2) < 0.6$; $n_2 = 2, 3, 4$; $k_2 = 2, 3$.

The computer model was developed in the program environment "Lazarus" for calculating the values of dependent variables, drawing graphics and monitoring the movement of blade tips (Free Pascal Lazarus project, Version #: 1.0.14).

## 3 Results and discussion

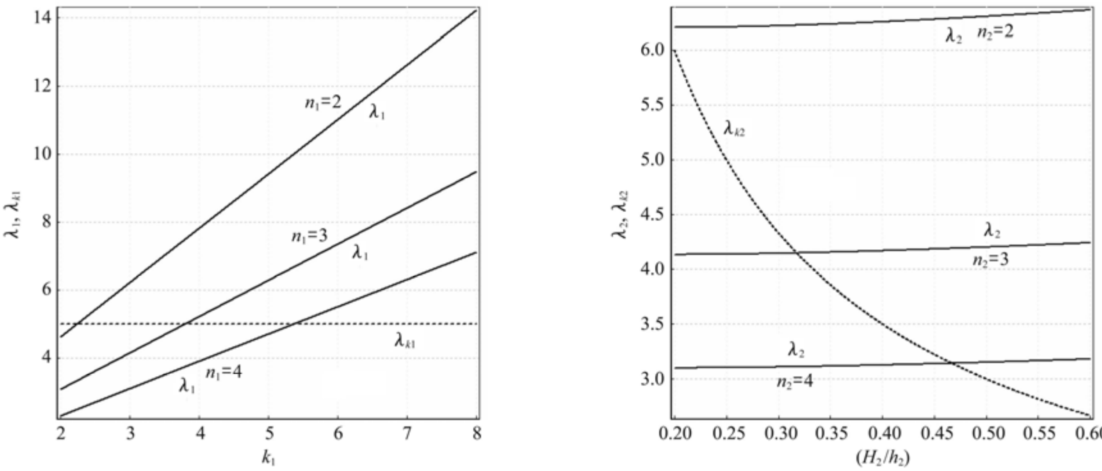
The front rotor was considered at first. One rotor rotary tiller did not provide equal sizes of an upper pierce of a slice, when $(H_1/h_1) = 0.25$ (Figure 3).

The height of an upper pierce of slice ($h_{m1}$) greatly exceeded the width of this pierce ($s_1$). As the number of blades on one side of a flange increased from 2 (Figure 3a) to 3 (Figure 3b), the difference between the height and the width also increased. The inequality 13 was correct at $n_1=2$, $k_1=3$ and at $n_1=3$, $k_1=4$ (Figure 4a).




(a) $n_1 = 2$ (b) $n_1 = 3$

Figure 3 Effect of $k_1$ on ($s_1/h_1$), ($h_{m1}/h_1$), ($h_{s1}/h_1$), when ($H_1/h_1$) = 0.25




(a) ($H_1/h_1$) = 0.25 (b) $k_2$ = 3

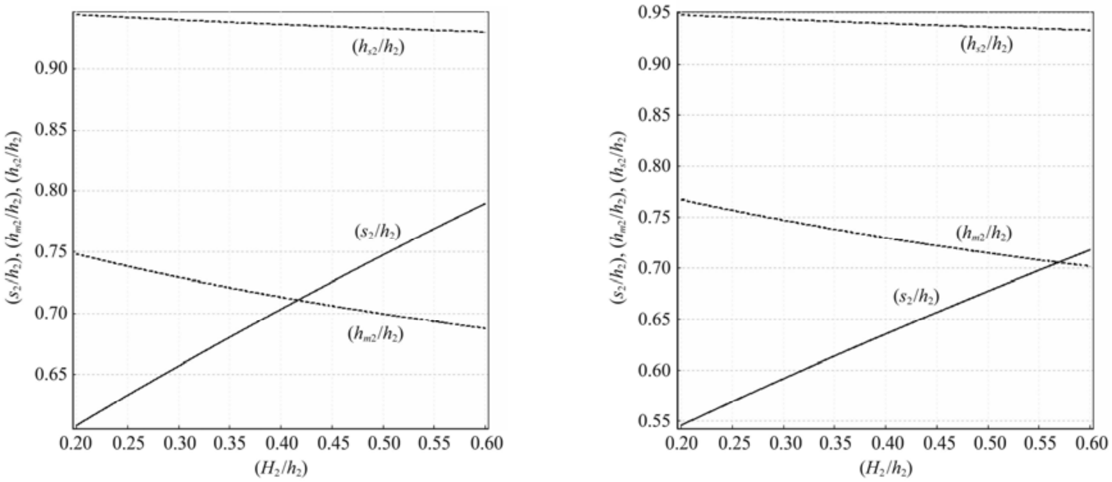
Figure 4 Effect of $k_1$ on $\lambda_1$, $\lambda_{k1}$ and effect of ($H_2/h_2$) on $\lambda_2$, $\lambda_{k2}$

The second option was preferable, because the values of the variables ($h_{m1}/h_1$), ($s_1/h_1$), $\lambda_1$ were less and the value of the variable ($h_{s1}/h_1$) was bigger. Thus, if the depth of tillage was equal to 200 mm, the height of upper pierce of a slice was not equal to the width of this pierce. The height exceeded 120 mm in this case. Therefore, one rotor rotary tiller cannot provide the equal sizes of pierces in the upper layer of soil. Moreover, this tiller cannot provide the height of these pierces less 80 mm without increasing ratio of relative blade tip speed to tractor forward speed $\lambda_1$ above 9.

Thus, second rotor can be useful to provide equal sizes of pierces in the upper layer instead of additional pass with lessened tilling depth. The rear rotor provided equal sizes of an upper pierce of a slice, when ($H_2/h_2$) ≈ 0.42 and $n_2=2$ (Figure 5a) or ($H_2/h_2$) ≈ 0.56 and $n_2=3$ (Figure 5b).

The second option was preferable, because the value of variable $\lambda_2$ was less (Figure 4b).

The calculated values of parameters of twin rotary tiller, providing tilling depth 200 mm and height and width of slice pierce in upper layer of soil 40 mm or 50 mm, were presented in Tables 1, 2. It can be seen, that radius of the rear rotor increased as the number of blades on one side of a flange increased. The rear rotor can be placed at the same distance between the horizontal axis and initial soil surface as the front rotor ($H_1=H_2=50$ mm). The radius of this rotor was equal to 122 mm. The height and width of slice pierces in high layer of soil after this rotor blade cuts were equal to 50 mm. Thus, the use of rear rotor helped to reduce sizes of pierces in the upper soil layer more than two times.




(a) $n_2 = 2$ (b) $n_2 = 3$

Figure 5 Effect of $(H_2/h_2)$ on $(s_2/h_2)$, $(h_{m2}/h_2)$, $(h_{s2}/h_2)$, when $k_2 = 3$

**Table 1 The values of the parameters of the front rotor**

| The given values | | | | The calculated values | | | | |
|---|---|---|---|---|---|---|---|---|
| $h_1$ (mm) | $H_1$ (mm) | $k_1$ | $n_1$ | $R_1$ (mm) | $\lambda_1$ | $s_1$ (mm) | $h_{m1}$ (mm) | $h_{s1}$ (mm) |
| 200 | 50 | 3 | 2 | 250 | 6.21 | 127 | 148 | 188 |
| | | 4 | 2 | 250 | 7.81 | 101 | 128 | 193 |
| | | | 3 | 250 | 5.67 | 92 | 132 | 194 |
| | 100 | 3 | 2 | 300 | 6.31 | 150 | 140 | 186 |
| | | | 3 | 300 | 4.64 | 135 | 143 | 187 |
| | | 4 | 2 | 300 | 7.97 | 118 | 118 | 192 |
| | | | 3 | 300 | 5.75 | 109 | 121 | 193 |

**Table 2 The values of the parameters of the rear rotor**

| The given values | | | | The calculated values | | | | |
|---|---|---|---|---|---|---|---|---|
| $k_2$ | $n_2$ | $h_2$ (mm) | $H_2$ (mm) | $R_2$ (mm) | $\lambda_2$ | $s_2$ (mm) | $h_{m2}$ (mm) | $h_{s2}$ (mm) |
| 3 | 2 | 56 | 23 | 79 | 6.26 | 40 | 40 | 52 |
| | | 70 | 29 | 99 | 6.26 | 50 | 50 | 65 |
| | 3 | 57 | 32 | 89 | 4.66 | 40 | 40 | 53 |
| | | 71 | 40 | 111 | 4.66 | 50 | 50 | 66 |
| | 4 | 57 | 41 | 98 | 3.85 | 40 | 40 | 53 |
| | | 71 | 51 | 122 | 3.85 | 50 | 50 | 66 |

## 4 Conclusions

1. One rotor rotary tiller does not provide equal sizes of an upper pierce of a slice, when ratio of distance between the horizontal axis of the rotor and initial soil surface to the tilling depth is equal to 1/4. If the rotor moves forward without soil resistance at the moment of blade entry in the soil, the height of an upper pierce of slice greatly exceeds the width of this pierce.

2. Twin rotary tiller can provide equal sizes of pierce of a slice in the upper layer of soil. Under tilling depth 200 mm the height and width of the pierce can be equal to 40 mm or less.

3. Radius of the rear rotor increases from 99 mm to 122 mm as the number of blades on one side of a flange increases from 2 to 4, and the height and width of pierce of a slice in the upper layer of soil are equal to 50 mm. The ratio of blade tip speed to forward tractor speed decreases from 6.26 to 3.85 under these conditions.

## References

Celik, A., and S. Altikat. 2008. Geometrical analysis of the effects of rotary tiller blade path on the distribution of soil slice size. *Applied Engineering in Agriculture*, 24(4): 409–413.

Celik, A., I. Ozturk, and T. R. Way. 2008. A theoretical approach for determining the irregularity of soil tillage depth caused by horizontal axis rotary tillers. *Agricultural Engineering International: the CIGR Ejournal*, Vol. X: Manuscript PM 08 003.

Dhruwe, N. K., S. Sahu, R. Raghuwanshi, and P. K. Nishad. 2018. Field performance evaluation of L-shaped blade rotary tiller cum inter row weeder. *International Journal of Agricultural Engineeing*, 11(1): 64–72.

Hendrick, J. G., and W. R. Gill. 1971a. Rotary-tiller design parameters: Part I. Direction of rotation. *Transactions of the ASAE*, 14(4): 669–674 and 683.

Hendrick, J. G., and W. R. Gill. 1971b. Rotary-tiller design parameters: Part II. Depth of tillage. *Transactions of the ASAE*, 14(4): 675–678.

Hendrick, J. G., and W. R. Gill. 1971c. Rotary-tiller design parameters: Part III. Ratio of peripheral and forward velocities. *Transactions of the ASAE*, 14(4): 679–683.

Hendrick, J. G., and W. R. Gill. 1978. Rotary-tiller design parameters: Part V. Kinematics. *Transactions of the ASAE*, 21(4): 658–664.

Korn, G. A., and T. M. Korn. 1968. *Mathematical Handbook for Scientists and Engineers*. 2nd ed. New York: McGraw-Hill Book Company.

Shamsabadi, H. A. T., D. Ahmad, and Y. Azmi. 2017. Yield components of sweet corn (*Zea mays*) and some soil physical properties towards different tillage methods and plant population. *Agricultural Engineering International: CIGR Journal*, 19(3): 56–63.

Shinde, G. U., and S. R. Kajale. 2012. Design optimization in rotary tillage tool system components by computer aided engineering analysis. *International Journal of Environmental Science and Dveopment*, 3(3): 279–282.

Zhang L., J. Wang, G. Fu, and Y. Zhao. 2018. Rotary tillage in rotation with plowing tillage improves soil properties and crop yield in a wheatmaize cropping system. *PLoS One*, 13(6): e0198193.