Headland turns using the tractor's "fifth wheel" steering device instead of front steering wheels

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Abstract

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Performance of nonworking moves by farming units in headland is associated with some expenditure of time, which reduces their productivity, as well as soil compaction leading to yield reduction. Both the reduction of length and duration of nonworking moves and reduction of the headland width are subject of numerous studies. Many manufacturers achieve this through various systems to reduce the radius of the turn of tractors and increase the speed of the front axle in turns. Recently a turning device has appeared in practice representing a fifth wheel located on the front mounting system of the tractor by means of which the turning is performed. This type of turning is applicable to mounted machines only. The present study describes various options of making turns with the tractor's fifth wheel and these are compared to the front wheel turns. The length of nonworking moves, the duration of their performance and the headland width have been determined. The results show the working widths of mounted machines where the use of a fifth wheel is effective.

Keywords: headland; turning device; type of turns; turning time; fifth wheel; length of nonworking moves; width of headland

Abbreviations:

B	working width of the unit, m
p. O	center of the turn (Fig. 2 and Fig. 3)
R	minimum radius of the unit, m
Lt	distance from the tractor's rear axle to the outer board of the tractor's fifth wheel mounted on the front mounting system, m (Fig. 2)
Lk	longitudinal base of the tractor (distance between front and rear axle), m (Fig. 2)
La	kinematic length of the unit (distance from tractor's rear axle to the last row of working units of the machine, m (Fig. 2)
α	central angle of a circle arc formed while the unit moves in the headland, degree
p. A	start of the nonworking move (Fig. 3)
p. C	making a turn with a fifth wheel (Fig. 3)
p. F	the beginning of a turn with the front steering axle (Fig. 3)
p. D	end of the nonworking move (Fig. 3)
AC, CF, *CD*	straight sections of the nonworking move
$\overline{\overline{CD}}, \overline{\overline{DN}}$	arched sections of the nonworking move

OC, CS	straight lines relating to the geometric construction of the turn
l	length of the nonworking turn in the headland, m
E	minimum theoretical width of the headland, m
Er	actual width of headland, m
k	number of moves for cultivating the headland
M	transverse width of the tractor, m
b, c, d	length of straight sections in the headland, m
Ω–turn	pear-shaped turn (Fig. 4a)
T–turn	fishtail turn (Fig. 4b)
Π-turn	sprawling turn (Fig. 4d)
t_u	time for tractor movement during nonworking move, s
t_o	time for turn using the tractor's fifth wheel, s
p	number of turns using fifth wheel in nonworking move
t_a	time for acceleration or deceleration of the tractor, s
t_{cv}	time for tractor movement at constant speed, s
t_s	idle time of the tractor for turning the steering wheels from 0 to maximum turning angle, s
n	number of accelerating and decelerating moves of the tractor
m	number of stops of the tractor for turning the steering wheels
v	speed of tractor movement, km h^{-1}
Δv	speed change in accelerating and decelerating tractor movement from 0 to *v*, km h^{-1}
a	acceleration, m s^{-2}
l_a	the distance covered by tractor in acceleration from 0 to *v* or deceleration from *v* to 0, m
t_w	time for accelerating and decelerating movement of the tractor when the constant speed set cannot be reached *v* (in short nonworking move), s
t_{a5}	time for accelerating or decelerating movement with fifth wheel, s
t_{ovc}	time for making a turn with a fifth wheel tractor and constant speed, s
t_{ud}	time for raising and lowering the fifth wheel, s
v_5	speed of movement of the tractor fifth wheel, km h^{-1}
$Δv_5$	speed change in accelerating or decelerating movement of the tractor fifth wheel, km h^{-1}
l_d	length of arc covered by the fifth wheel in making a tractor turn, m (see Fig. 1)
l_{a5}	part of arc length l_d covered in accelerating from 0 to v_5 or decelerating from v_5 to 0, m

1. Introduction

In operation, farming units perform both working and auxiliary (nonworking) moves. In nonworking moves they make transition from one work move into the next one and that relates to making turns in the two opposite field ends, in the so-called manoeuver strips (headlands). The type of turns and their length determines the time for making nonworking moves and the width of headland. The time for making nonworking moves has direct effect on productivity of agricultural machinery, fuel consumption and the end economic results. The width of headlands also affects the final economic results. The land in the headlands becomes overcom-

pacted by the manoeuvering machinery resulting in drastic reduction of production yield from them. In perennials these headlands are only used to manoeuver the machines and the agricultural area is not used in a rational way.

In order to reduce the time of nonworking moves and the width of headlands modern manufacturers of wheel tractors use different systems to increase the manoeuvering capacity by reducing the turn radius. Landini in the tractor series Globus use „Fast run" system. In angle of turn of the front wheels over 35° the speed of the front axle increases by 78% which reduces the turn radius and the time of turning reduces by 30% (Delchev, 2003). Similar is the "Bi-speed Turn" system of Kubota (Ikegami et al., 1990). In the New Holland

tractors the „Super Steer" system is used in which a wheel turn angle of 65° is achieved by additional turning of the entire front axle at 19° to the longitudinal tractor axle (Carrier, 2013). JCB in the Fastrac tractors of the series 2000 and 4000 apply control on the front and rear axle, i.e. all 4 wheels are steering (JCB Agriculture, 2015). Also, in order to reduce the time of nonworking moves a system is used for reducing the number of steering wheel turns from four to two for full turn of the wheels in a headland. Usually that system combines with a system for automatic performance of operations at the headland (Headland Turn Assist) (Rickard, 2014).

In the practice a substandard system for increasing the manoeuverability of machinery units in the headland is applied by using the so-called "fifth wheel" of the tractor (Toppaolo, 2009; AgroTeamŁużna, 2015). On the front mounting system, perpendicular to the longitudinal tractor axis is installed wheel driven by a hydromotor (Fig. 1). At the end of the work stroke the wheel lowers down to the ground, the front axle of the tractor is raised, the hydromotor is triggered and the tractor turns round the centre of its rear axle. Turning continues until a position of the tractor is reached as close as possible to the next stroke. The hydromotor switches off, the front mounting system raises the wheel in which the front axle of the tractor is lowered to the ground. The tractor is directed to the next stroke. Simultaneously with lowering or raising the fifth wheel, the operator can perform raising of the working machine in transport position or lowering it in working position, respectively, depending on which part of the nonworking move the fifth wheel is used in. Also all operations in the headland, including raising, lowering and driving the fifth wheel can be programmed and performed automatically in most of the modern tractors.

Fig. 1. Tractor with fifth wheel for making turns

The main difference in making a turn using the fifth wheel from a kinematic point of view is the location of the center of the turn. In turn with a front steering axle, the center of the turn (point O) is located at the intersection of the axes of

the front wheels with the axis of the rear axle (Fig. 2a). The turn radius R is the distance from the center of the turn to the intersection of the tractor rear axle with its longitudinal axis (unit centre). When making a turn using a fifth wheel the centre of the turn is in the intersection of the tractor longitudinal axis with its rear axle (Fig. 2b). Since that point is also the unit centre, the theoretical radius of a turn is 0. This method of making a turn in the headland is interesting from the point of view of reducing the length of the nonworking move (turns) in the headland, and hence reducing the soil compaction in that area of the field. The use of this method of turning could lead to a reduction of the headland width for turning in some units.
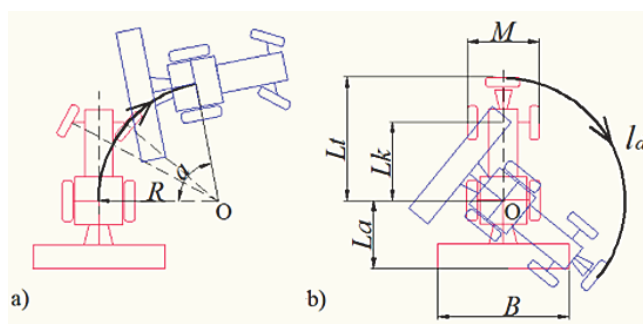

Fig. 2. Turn centre of a unit – (*a*) using front steeling axle, (*b*) using fifth wheel

The fifth wheel as a tool for turning in tractors is not very known and not common in practice. It is not marketed as a finished product. In literature there are no studies related to the kinematics of a turn using that wheel and the trajectories, the width of the headland and the time for performing nonworking moves are not known.

The article deals with and establishes the lengths of nonworking moves, the minimum theoretical headland width, the actual headland width and the time to perform the nonworking move using the tractor fifth wheel for options of ratio between the working width of the unit and its minimum turn radius. These options are compared to the options in which standard control of the tractor through the front axle is used.

2. Method

To study and evaluate the use of a fifth wheel we carried out a comparative analysis of manouevring (movement) in the headland using a fifth wheel for steering and front steering wheels of the tractor. Since there are no studies related to steering units by using a fifth wheel, we developed the possible trajectories of movement in the headland. They were developed for the four ratios (options) between the working

width of the unit and the radius of the turn. The length of the nonworking move, the minimum and actual headland width have been determined. These parameters have been set for the most used conventional ways of movement of mounted units in the headland with front wheel steering. In some publications the trajectory of movement in the nonworking move is described by the straight sections, curved sections with constant turning radius and connecting intermediate curves with variable radius (clothoids) (Sabelhaus et al., 2013). The length of the connecting intermediate curves is small compared with the total length of the nonworking move. Clothoids are obtained by changing the direction of the tractor while moving. Other authors study the trajectory of the nonworking move without clothoids (Spekken et al., 2015). To carry out nonworking moves without clothoids, only with straight and curved sections with radius equal to the minimum radius of the tractor turn, it is necessary to stop the unit and change the angle of turning of the wheels at standstill. Therefore, slowing down, stopping and acceleration will be done at each change of direction. In our study we assume that farming units will have to stop before any change of direction of movement and change of the angle of turning of the wheels will be performed at standstill, therefore the trajectories of nonworking moves will have no clothoids. This assumption is closer to reality when making turns with the fifth wheel, when unit also stops. In determining the time for making thee nonworking move the time necessary for turning the steered wheels of the tractor should also be taken into account. When using a fifth wheel it also takes time to lower the wheel, turn the tractor and raise the wheel.

2.1. Determining the length of the nonworking move and the headland width

2.1.1. Making nonworking moves by using fifth wheel on the tractor

The trajectory of the nonworking move has different shape depending on the ratio between work width of the unit B and minimum radius of a turn R. The different options of movement are shown on Fig. 3.

Option 1. B < R

The trajectory of the nonworking move consists of a straight section AC and arc $\overline{\overline{CD}}$ with radius R (Fig. 3a). The figure shows that $\cos \alpha = \dfrac{OS}{OC} = \dfrac{R - B}{R}$, therefore $\alpha = \cos^{-1}\left(\dfrac{R - B}{R}\right)$, i.e. $\alpha < 90°$. The lengths of the various sections in the nonworking move are respectively

$$AC = CS - 2.La = R.\sin\alpha - 2.La \tag{1}$$

$$\overline{\overline{CD}} = \frac{\pi.R.a}{180} \tag{2}$$

The length of turn is calculated at

$$l = AC + \overline{\overline{CD}} = R.\sin\alpha - 2.La + \frac{\pi.R.a}{180} \tag{3}$$
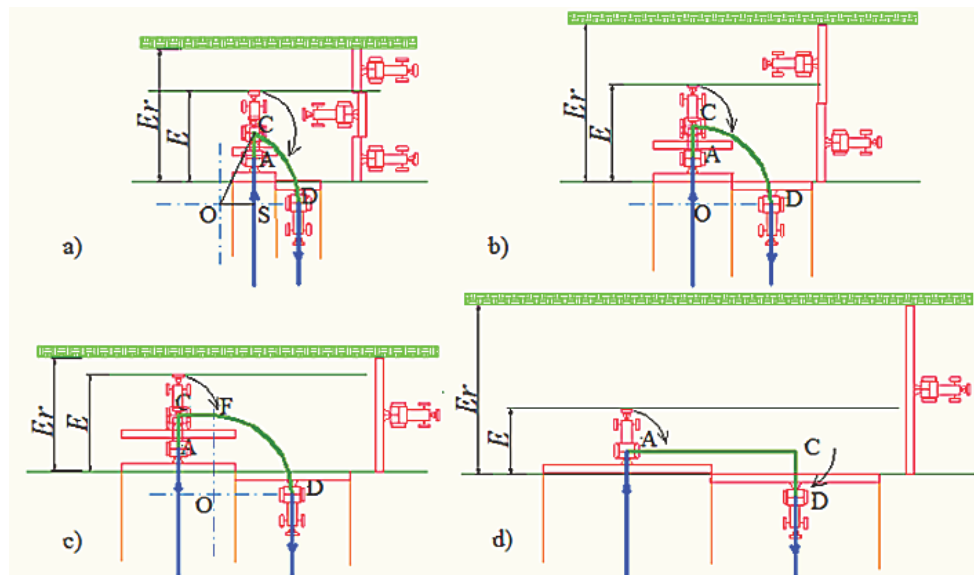

Fig. 3. Types of turns made in the headland by using the tractor's fifth wheel in different operational width of the unit:
a – Option 1, B < R; b – Option 2, B = R; c – Option 3, B > R; d – Option 4, B ≥ 2R

The minimum theoretical headland width is

$$E = CS + Lt - La = R.\sin\alpha + Lt - La \qquad (4)$$

Option 2. B = R

This is the border case of Option 1, where $\alpha = 90°$ (Fig. 3b). The straight and arc-shaped sections of the nonworking move has greater length but are determined by the same formulas as in Option 1. When we substitute $\alpha = 90°$ in them, we obtain

$$l = AC + \overline{\overline{CD}} = R - 2.La + \frac{\pi.R}{2} \qquad (5)$$

$$E = CS + Lt - La = R + Lt - La \qquad (6)$$

Option 3. B > R

The straight and arc-shaped sections retain the same length as in Option 2, but another straight section appears between them $CF = B - R$ (Fig. 3c). The length of the turn changes and is determined by the formula

$$l = AC + CF + \overline{\overline{FD}} = R - 2.La + B - R + \frac{\pi.R}{2} =$$
$$= B - 2La + \frac{\pi.R}{2} \qquad (7)$$

The headland width remains as in Option 2, i.e. $E = R + Lt - La$.

Option 4. B ≥ 2R

In that option (Fig. 3d) turns are to be made with the fifth wheel only – two turns at 90°. The length of the nonworking move and the minimum headland width shall be determined by the formulas

$$l = AC + CD = B + 2.La \qquad (8)$$

$$E = Lt + La \qquad (9)$$

The length of the nonworking move is small, but two stops are made for lowering and raising the fifth wheel, which will increase the duration.

In Option 3 the arc-shaped section of the nonworking move can be avoided by two turns with a fifth wheel. The appropriateness will depend on the specific parameters of the unit.

2.1.2. Conventional ways of movement of units in the headland

The main ways of performing nonworking moves of units in the headland are shown in Fig. 4. With small operating width of the unit ($B < 2R$), the movement for performing nonworking moves in the headland can be with forward or forward and reverse move. When movement is performed only with forward move, the result is the so-called pear-shaped turn (Ω-turn) (Fig. 4a). It, as well as its derivatives (laterally displaced pear-shaped curves) have very great length, and in the type shown in the figure, very large head-
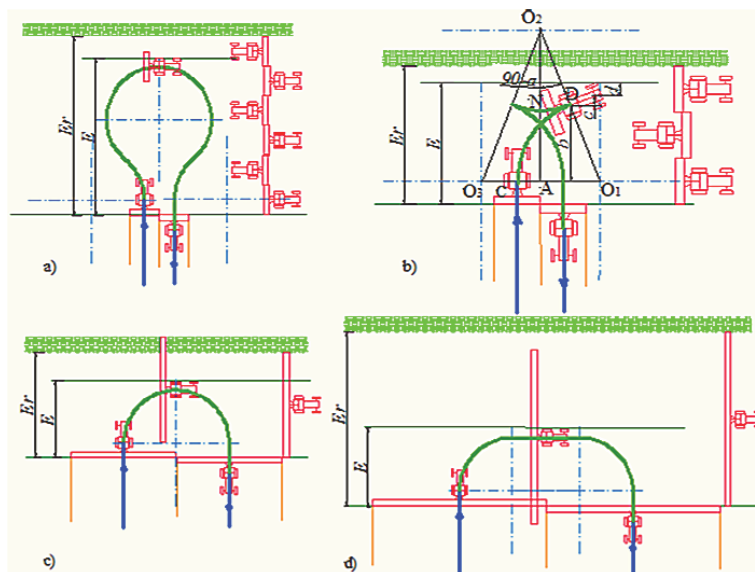
Fig. 4. Conventional types of turns performed by units in the headland:
a – pear-shaped turn (Ω-turn); *b* – fishtail turn; *c* – along semi-circle; *d* – sprawling turn (Π-turn)

land width is also required. In mounted machines this kind of movement is rarely used and therefore will not be discussed.

2.1.2.1. Fishtail turn with slope

Most often mounted units make nonworking moves, in which part of the movement is in reverse – fishtail turns. This movement can be with straight (T-turn) or curvilinear trajectory (fishtail-turn), and curvilinear trajectory is most often used in reversing. Thus, the front part of the unit is directed to the field before it enters it. Fishtail ways of movement can be open or closed (with or without a loop). With the closed way of movement the first and the last move of the unit intersect and therefore the nonworking move has smaller length (Fig. 4b). Another advantage that makes the closed fishtail movement (fishtail-turn) preferred is that the first turn after finishing the working move is in the direction of the untreated portion of the field, which always remains within the driver's sight.

Fig. 4b shows that $\cos \alpha = \dfrac{O_1A}{O_1O_2} = \dfrac{R - 0,5.B}{2.R}$, i.e. $\alpha = \cos^{-1}\left(\dfrac{R - 0,5.B}{2.R}\right)$. The length of the non-working move and the minimum theoretical headland width are determined by the dependencies:

$$l = 2\overline{\overline{CD}} + 2\overline{\overline{DN}} + 2.La = \pi.R + 2.La \quad (10)$$

$$E = b + c + d + La = (R + 0,5M).\sin \alpha + Lk.\cos \alpha + La \quad (11)$$

2.1.2.2. Semi-circle turn

With operating width $B = 2R$ a semi-circle turn is made (Fig. 4c). Its length is $l = \pi.R + 2.La$, i.e. the same as in the fishtail turn on Fig. 4b. The minimum headland width in the mounted machine is

$$E = R + 0,5M + La \quad (12)$$

2.1.2.3. Sprawling turn (П-turn)

When the working width is $B > 2R$ a sprawling turn is made (П-turn) (Fig. 4d). Its length is determined by the equation $l = \pi.R + B - 2.R + 2.La = 1,14. R + B + 2.La$, and the headland width is determined as in the semi-circle turn (Fig. 4c).

2.1.3. Actual headland width

The headland width is handled in one or several moves of the unit in parallel to the field border. The number of moves can be determined by the relation $k = E/B$, the result being rounded to the bigger integer. The headland width has to be multiple of the operating width of the unit, therefore the actual width is $Er = k.B$.

2.2. Time for performing nonworking moves

When calculating the time for making nonworking moves most authors accept that the movement is carried out at a constant speed without acceleration and deceleration since agricultural machines operate at motor constant speed (Spekken et al. 2015). Changing speed can be caused by possible gear switching, but the difference is small and the impact is negligible. Just when making a fishtail turn with straight reverse move (T-turn) to the time for stopping and change of direction of movement is added the time for deceleration. In the present work the time for making nonworking moves is calculated using a methodology similar to that described in (Sabelhaus et al., 2013) and at the same values of speed and acceleration of the tractor. Calculations are made for tractor speed $v = 6$ km h^{-1} and acceleration $a = 1,5$ m s^{-2}. The change of the speed of movement of the tractor is $\Delta v = 6 - 1 = 6$ km h^{-1}.

The time the unit travels at constant speed and time during acceleration or deceleration of the tractor, as well as the time for turning the wheels to change the direction of movement of a stopped tractor is taken into account. The duration of the nonworking move includes the time for movement of the tractor during the nonworking move and the time for making a turn using the tractor's fifth wheel

$$t = t_u + p.t_0 \quad (13)$$

2.2.1. Time for movement of the tractor during nonworking move

$$t_u = n.t_a + t_{cv} + m.t_s \quad (14)$$

2.2.1.1. Time for accelerating or decelerating movement of the tractor

$$t_a = \frac{\Delta v}{3,6.a} \quad (15)$$

2.2.1.2. Time for movement at constant speed

$$t_{cv} = \frac{(l - n.l_a).3,6}{v} \quad (16)$$

$$t_a = \frac{a.\,t_a^{\,2}}{2} \quad (17)$$

When the length of the nonworking move is less than the distance needed for accelerating and decelerating movement of the tractor ($l < n.l_a$) and the speed set for uniform movement cannot be reached (in this case $v = 6$ km h^{-1}), the entire length of the nonworking move is covered in accelerating and decelerating movement. In this case formula (14) has the following expression

$$t_u = t_w + m.t_s \quad (18)$$

$$t_w = \sqrt{\frac{2.l}{a}} \qquad (19)$$

2.2.1.3. Time for turning of the steering wheels.

It is assumed that $t_s = 3$ s when the wheels turn from 0 to the maximum angle or reverse. When wheels turn from maximum angle in one direction of turning to maximum angle in the other direction, the time is assumed to be $t_s = 6$ s. During turn of the wheels the raising of the working machine in transport position can be performed or it can be lowered in work position. Due to that the time for raising or lowering the working machine is not calculated separately.

2.2.2. Time for turning the tractor using the fifth wheel

$$t_0 = 2.t_{a5} + t_{ovc} + 2.t_{ud} \qquad (20)$$

2.2.2.1. Time for accelerating or decelerating movement of the fifth wheel

$$t_{a5} = \frac{\Delta v_s}{3,6.a} \qquad (21)$$

Calculations were done at speed of movement of the fifth wheel $v_s = 4$ km h^{-1} and accelerating $a = 1,5$ m s^{-2}. The change of speed at accelerating or decelerating movement of the tractor's fifth wheel is $\Delta v_s = 4 - 0 = $ km h^{-1}.

2.2.2.2. Time for making a turn with the tractor using the fifth wheel and constant speed of the wheel

$$t_{ovc} = \frac{(l_d - 2.l_{a5}).3,6}{v_s} \qquad (22)$$

$$l_d = \frac{\pi.Lt.(180 - a)}{180} \qquad (23)$$

$$l_{a5} = \frac{a.t_{a5}}{2} \qquad (24)$$

2.2.2.3. Time for lowering or raising the fifth wheel

This is the time for lowering the fifth wheel onto the ground when the tractor's front axle is lifted, respectively the time for raising the fifth wheel and lowering the front axle to the ground. Simultaneously by lowering or raising the fifth wheel, raising or lowering the working machine can be done, and therefore this time is not reported separately. It is assumed that the times for raising and lowering are equal $t_{ud} = 5$ s.

Upon comparison of the various ways of movement of units within the headland the following values of the unit parameters were used: $R = 5.5$ m; $La = 2$ m; $Lt = 4.5$ m; $Lk = 3$ m; $M = 2$ m; $B = 1 \div 36$ m. It has been assumed that work width varies within very wide boundaries in order to cover the various types of mounted machines – from ploughs of small width to fertilizer spreaders and sprayers with great work width.

3. Results

3.1. Movement using the fifth wheel

The results about the length of nonworking move, the minimum theoretical and actual width of the headland are shown in Fig. 5. It is seen that with large working width (Option 4, $B \geq 2R$) all functions are linear – the length of the nonworking move and the actual width of headland grow proportionally to the working width. Since $E < B$, the cultivation of the headland will be performed at one move of the unit, hence $Er = B$.

In Option 3 ($B > R$) the length of nonworking move l also increases linearly depending on the working width, which is due to the increase of the rectilinear section CF
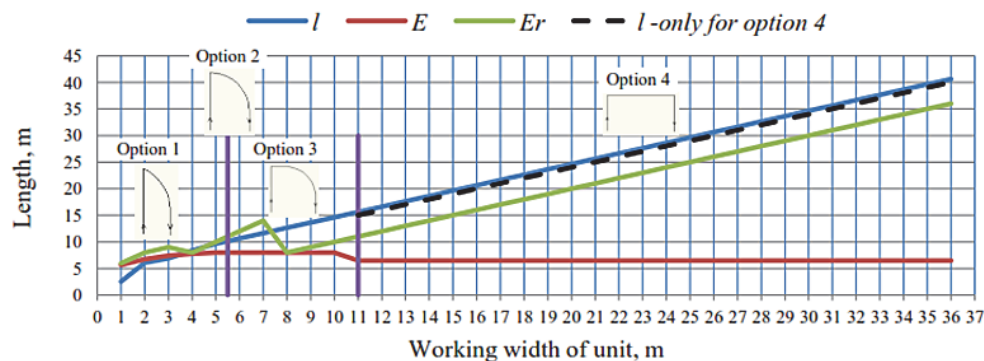

Fig. 5. Length of the nonworking move and width of the headland in moves performed by using the tractor's fifth wheel

(Fig. 3c). With working width $B \geq 2R$ the length of non-working move is similar and slightly larger than that of Option 4. This is due to the fact that in Option 3 one turn with a fifth wheel and one with a front axle are performed, while in Option 4 both turns are performed with a fifth wheel. The actual width of the headland changes and in small working width and $B < E$ the headland is cultivated with two or more moves of the unit, while in larger working width and $B > E$ the headland is cultivated with one move.

The smallest length of the nonworking move and the smallest width of the headland is obtained in Option 1 ($B < R$), i.e. in small working width of the unit. Here, however, the number of moves for cultivating the headland increases by reducing the working width. With width of the unit 1 m and minimum theoretical width of the headland of 5.66 m a total of 6 moves of the unit are necessary for cultivating the headland, which means greater cost.

In general, it can be concluded that the performance of nonworking moves in the headland by using the tractor's fifth wheel is the most suitable for small working widths, close to the radius of the turn of the unit, i.e. $B \leq R$ (or between the upper limit of Option 1 and Option 2), since in this case the headland is processed by two moves performed by the unit.

When the unit has greater working width (Option 3 and Option 4), the length of the nonworking move can be equal depending on the radius of the unit R. On Fig. 6a is the diagram presenting the change in the length of the nonworking move depending on R. The calculations have been made for working width $B = 6$ m by keeping the other values of the unit parameters and change in the radius of the turn from 3 to 9 m. The figure shows that with certain value of R the lengths of nonworking moves in both options are equal. That value of R can be determined by dependences (7) and (8) concerning the lengths of nonworking moves in both options. After making them equal we obtain $B - 2.La + \dfrac{\pi.R}{2} = B + 2.La,$ therefore in $R = 8.La/\pi$ the length of the nonworking moves in both options is equal. In this case this is at $R = 5.1$ m. With that radius regardless whether at the end of the nonworking move there is an arc-shaped or straight section, the length of the non-working move in the headland is the same and in this case equal to 10 m.

The minimum theoretical width of the headland in Option 3 and Option 4 is calculated with $R = 2.La$, in this case $R = 4$ m (Fig. 6b). The headland is cultivated with one move of the unit when $E = B$. For Option 3 that is obtained with R $\leq B - Lt + La$. Fig. 6c shows that in $R \leq 3.5$ m in Option 3 the actual width of the headland will be at width $Er = B = 6$ m,

while in Option 4 regardless of the radius of a unit turn $Er = 2.B = 12$ m, since $E = 6.5$ m (Fig. 6b).

Therefore, the ratio between the kinematic length and the radius of the unit turn determines which of the options 3 and 4 will be preferred. Option 3 has smaller length of the nonworking width at $R < 8La/\pi = 2,55La$, while at $R < 2La$ and with smaller width of the headland compared to Option 4.
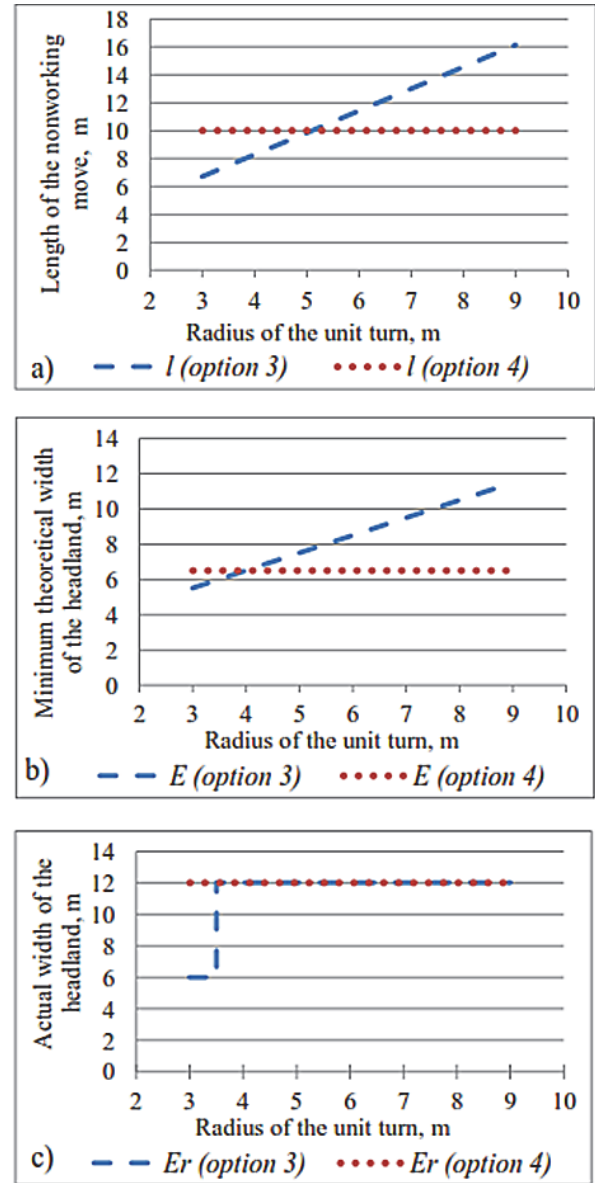

Fig. 6. Length of the nonworking move (*a*), theoretical (*b*) and actual (*c*) width of the headland at constant working width depending on the radius of a unit turn
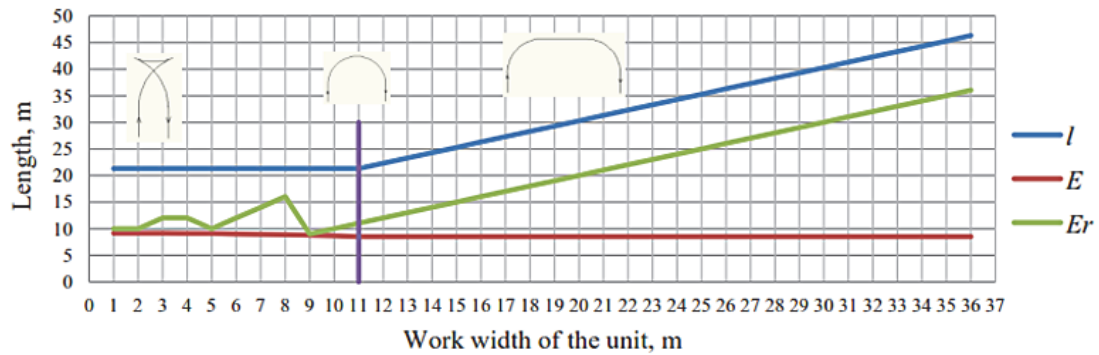
Fig. 7. Length of the nonworking move and width of the headland in performing traditional turns with front steering axle
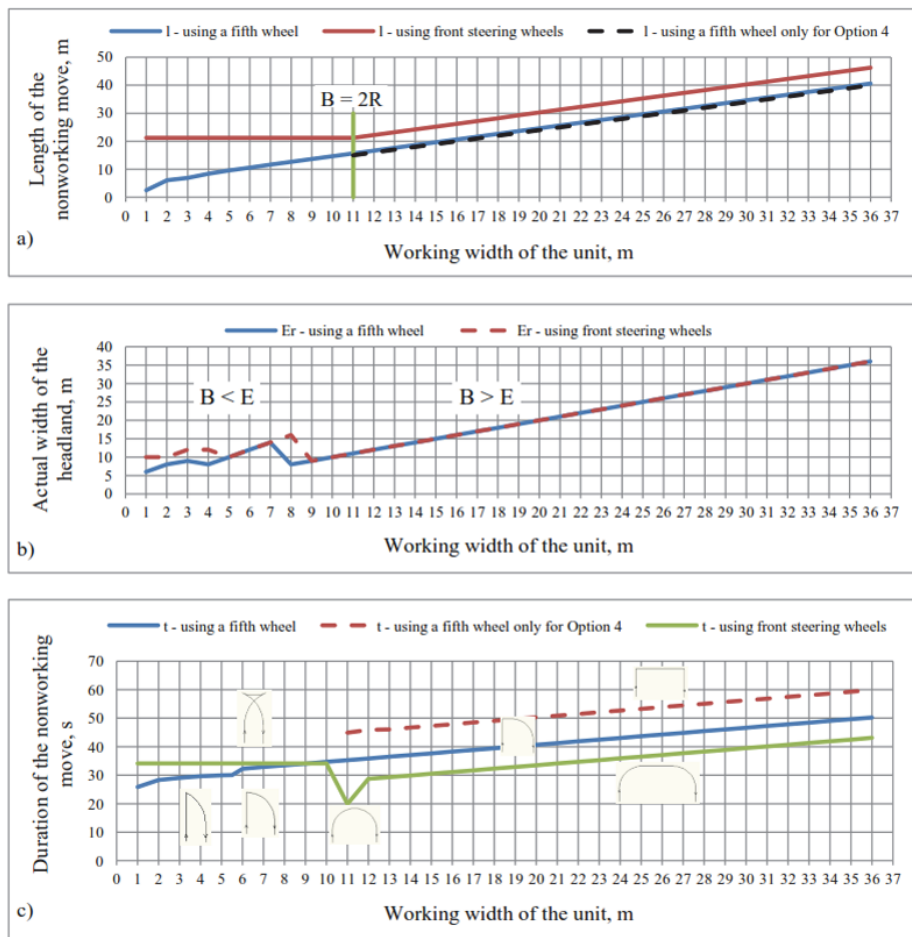

Fig. 8. Comparison of the length of the nonworking move (*a*), the actual width of the headland (*b*) and the duration of the nonworking move (*c*) in turns with front steering axle and by using a fifth wheel

3.2. Performing turns with front steering axle (traditional turns)

Fig. 7 shows the results for length of nonworking move, minimum and actual width of the headland when perform-ing traditional turns. It is obvious that the fishtail turn and the semi-circle turn have the same length up to $B = 2R$ or $B = 11$ m. In $B > 2R$ the length of the nonworking move and the actual width of the headland increase proportionally to

the working width of the unit. When $B < 2R$ the headland is cultivated with several moves of the unit and the number of moves increases by decreasing the width. It is obvious that the theoretical width E of the headland changes insignificantly by changing the type of turn and the working width. With $B > E$ the headland is cultivated with one move of the unit, in this case that is with working width $B > 8.75$ m. When growing certain crops some of the operations do not require headlands in the field and the nonworking moves are performed on the roads round the field or specifically laid inner roads within the crop area for servicing the units. In this case the value of E can be used for designing the width of these roads.
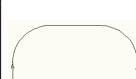
3.3. Comparison between turns with front steering axle and by using a fifth wheel in the headlands

Fig. 8a shows that the length of the nonworking move in performing turns by using a fifth wheel is smaller than turns by front steering axle within the entire range of the studied working widths of the mounted unit. With small widths ($B < 2R$) that difference is non-significant. With working width under 6 m, the length of the working move is over 2 times less. Usually such is the working width of mounted soil cultivating machines, aggregated to tractors with power 100 to 250 hp. Especially great is the difference at the smallest working widths and with such widths are the ploughs for deep ploughing, widely used in countries with severe soil conditions. Performing turns by using a fifth wheel will dramatically shorten the length of the nonworking move and when working in perennial crops, especially vineyards, where machines with small width are used and the spacing is most often between 2-2.5 m.

The actual width of the headland (Fig. 8b) when using a fifth wheel is smaller compared to that at turns with the front steering axle at working width of the unit up to 9 m. Exceptions are working widths from 5 to 7 m. With working width of the unit over 9 m headlands have equal width, regardless of how the turn is made (with front axle or by using a fifth wheel). Nevertheless, it should be borne in mind that in turns using a fifth wheel the lengthy of the distance travelled in these headlands is significantly shorter and thus soil compaction by machines will be less.

Table 1 lists some of the parameters necessary to calculate the duration of nonworking moves and the results of the calculations are given in Fig. 8c. The duration of the nonworking moves by using a fifth wheel compared to front steering wheels is less when using mounted machines with working width up to 9.5 m, the difference being more significant in small working widths (Option 1 and Option 2). In larges working widths (over 9.5 m) the duration of the

Table 1. Values of some parameters in determining the time for making nonworking moves

Type of turn	Number of accelerating and decelerating moves of the tractor, n	Number of stops of the tractor for turning the steering wheels, m	Number of turns using fifth wheel in nonworking move, p
	3	1	1
	3	1	1
	5	2	1
	3	0	2
	6	6	0
	2	2	0
	6	4	0

nonworking moves by using a fifth wheel is greater. This is due to the additional stopping time, lowering or raising the fifth wheel. In Option 4 the tractor's fifth wheel is used twice to turn and therefore the duration of the nonworking move is greater compared to Option 3, where it is used once.

Conclusions

Using the fifth wheel of the tractor to make turns in units is an alternative to the conventional way of making turns in headlands. The results of the comparison of the two units (with a fifth wheel and front steering wheels with the accepted parameters) showed that by using a fifth wheel better basic kinematic parameters of the mounted units with small and medium-sized work width of up to 9-11 m are provided. Smaller length of the nonworking moves, respectively less time for their completion and smaller headland width are achieved. These indicators are a prerequisite for higher productivity, less soil compaction in headlands and higher yields from them. Practically most mounted machines (ploughs,

cultivators, seeders, etc.) do not have large working width. Using the fifth wheel of the tractor to perform turns is irrational in the mounted farming machines with large working width such as fertilizer spreaders, sprayers, etc.

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