RESEARCH OF POSSIBILITIES FOR EFFICIENT USE OF WIDE SPAN TRACTOR (VEHICLE) FOR CONTROLLED TRAFFIC FARMING

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Abstract. In part, the economic effect gained from the introduction of controlled traffic farming can be directly determined by the area of the field lost under the engineering (or traffic) zone of the vehicles involved. With a wide span tractor, as with other vehicles, the area lost under the traffic zone will depend upon how efficiently operations in the field are organised. The purpose of the present investigation is to substantiate the design and other parameters of the wide span tractor from a position of efficient land use in controlled traffic farming. Theoretical studies, synthesis of the construction diagram and parameters of the wide span tractor were carried out using computer simulation of its operation. These studies indicated that planning of the field for controlled traffic farming with the use of a wide span tractor should take into consideration its track width and its field operational parameters. The use of a contemporary design of wide span tractor with a track width more than 7.5 m results in field traffic zone losses of no more than 5 -6 %, which is quite acceptable. Practical use of a wide span tractor for controlled traffic farming needs automatic steering to reduce field traffic zone area losses by a factor of 1.5 times compared with manual steering.

Keywords: controlled traffic farming, wide span tractor, wide span vehicles, bridge (gantry) agriculture, engineering zone, land use, technological track.

Introduction

By using agricultural machinery with different working widths most of the fertile soil (around 75 % of the area) is subject to the unfavourable impact tractor and machinery wheels [1]. Controlled traffic farming (CTF) is a system, which confines all machinery loads to the least possible area of permanent traffic lanes [2].

The efficiency of controlled traffic farming is higher, if there are less unproductive parts of the field designed for the engineering zone. The latter, as it is known, is determined by the pass, which depends on the track width and the parameters of the actuators of the undercarriage of the wide span tractor. Naturally, an increase in the track width of the latter has a positive effect on the land use indicators in controlled traffic farming, yet it is becoming more problematic technically to design such machines and to automate the control of their movement. Therefore, it is purposeful to increase the track width of wide span tractors to a definite value, which allows having satisfactory land use indicators in controlled traffic farming.

The world science has already accumulated certain experience in the items of studying and practical implementation of controlled traffic farming [2-7]. The technological basis of these systems are wide span vehicles or wide span tractors [8-11]. There is considerably increased interest in wide span tractors recently. Their development is the aim of scientists in the USA, Great Britain, Japan, Poland, the Netherlands, Russia, Ukraine, and many other countries [12].

Among the widely known models of wide span tractors a tractor should be mentioned with a 6 m track width, controlled by the laser guidance system [12]. In Israel, on the basis of a tractor with a 180 HP engine, a wide span vehicle has been created having a 5.8 m track width [8]. In Sweden, the companies TEC and Biovelop AB have developed a concept of a wide span tractor «BIOTRAC» with a 10 m track width, intended for controlled traffic farming [13]. The track width of a specialised wide span tractor for plant cultivation is 12 m [1]. The wide span tractor ASA-Lift WS 9600 WS has a track width of 9.6 m [10]. The Brazilian Science and Technology Laboratory of Bioethanol (CTBE) presented to the world a wide span tractor ETC with a 9 m track width designed for growing sugar cane [9]. The scientists of Ukraine have developed wide span vehicles for controlled traffic farming with a track width of 3 m [15]. Theoretical foundations of the use of various machines and tools can be based on the research results by [16].

Analysis of scientific publications indicates that the value of the track width of a wide span tractor may vary from 3 m to 21 m. It is clear that at such a range of the track width the losses of the field under the engineering zone change in inverse proportion. The nature of this relationship depends on many factors, including the parameters of the wide span tractor. In terms of acceptable losses of the area of the field under the engineering zone, it is desirable to have acceptable methodology and to know how to determine the point of rational optimum of the track width for the wide span tractor.

The aim of this investigation is justification of the design and other parameters of wide span tractors from the position of efficient land use in controlled traffic farming.

Materials and methods

Theoretical investigations, synthesis of the constructive schemes and parameters of a wide span tractor were carried out by simulating the conditions of its operation on the PC. The basis for the research methods are the foundations of higher mathematics and theoretical mechanics, using the Mathcad packet [17].

Let us look at the field map of controlled traffic farming for wide span tractors, paying attention to the coordinate transport principle of their travel across the plot of land of rectangular regular configuration (Fig. 1).

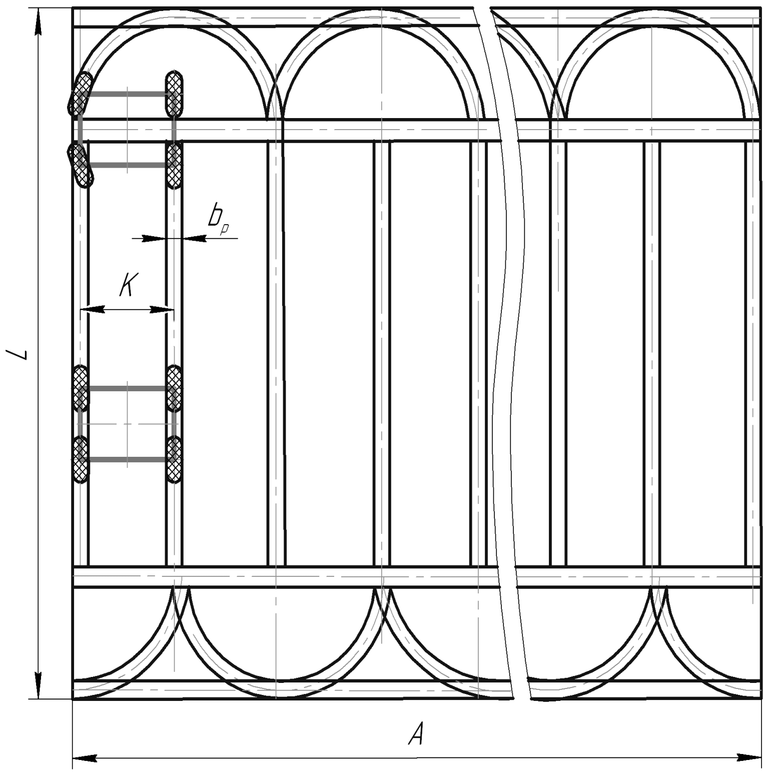

Fig. 1. **Field map of controlled traffic farming for wide span tractors**

It is purposeful to the change the direction of the movement of the wide span tractor on the headland with its circular turn [17]. Besides, the turning centre of the wide span tractor should be in the zone of the transport technological track of one of its boards (the left or the right one, depending on the direction of the turn). Only in this case it is possible to obtain the desired minimal radius of the turn and the width of the headland. In this case, with such a method of turning, a shift to the following pass of the wide span tractor takes place with a minimum period of time, which raises the labour productivity.

Technically, this type of turn can be implemented in two ways: 1) by kinematic turning of the platform of the wide span machine (Fig. 3), or by kinematically-forced turning in a raised position of one of the sides of the machine (Fig. 4). In the first way of turning (Fig. 3), a special pivot is used to turn the frame, and the inner wheels remain immobile during the turn. In the second variant (Fig. 4), the inner side (board) with the wheel of the wide span machine rises on a support, which has a special pivot with a support (but end) bearing, around which the turn is made. In addition to it, the support is also pivotal, it has support bearings, therefore it will not turn into the ground.

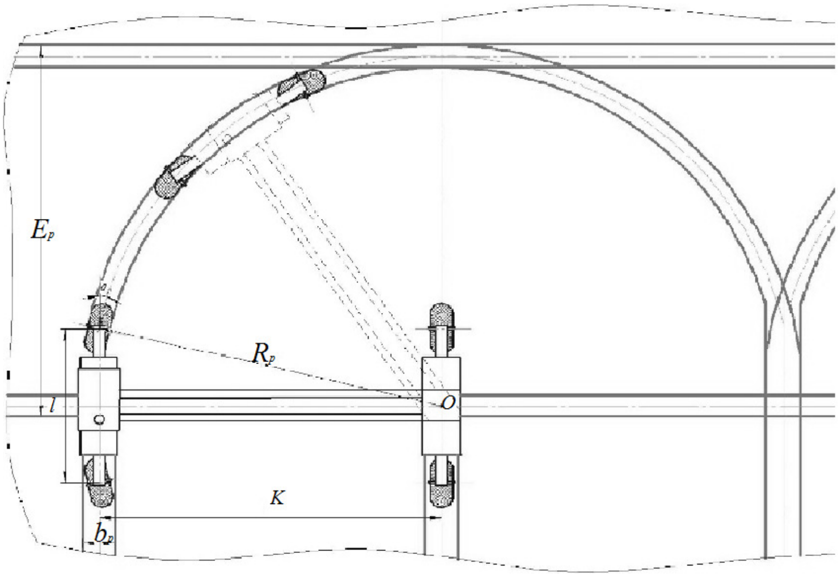

Fig. 2. **Schemes of the turn of a wide span tractor (vehicle) around the turning centre of the space between the wheels of one of the boards**

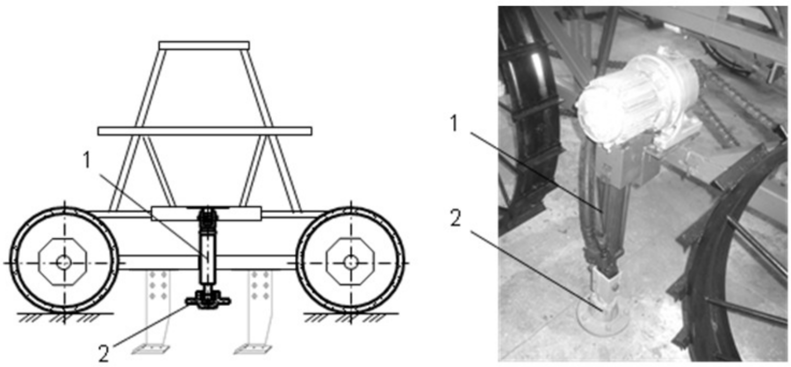

Fig. 3. **Forced turning of a wide span tractor (vehicle) by its suspension on the support:**
1 – hydraulic cylinder; 2 – support platform (plate)

We will estimate the losses of the area of the field under the engineering zone (w_i) according to Fig. 1 by a relative indicator, which is numerically equal to the relation of the engineering zone to the entire area of the field:

$$w_i = \frac{S_i}{A \cdot L}, \tag{1}$$

where S_i – area of the engineering zone of the field;
L and A – length and width of the field.

Then the coefficient of the land use (k_s) will be equal to:

$$k_S = 1 - w_i = 1 - \frac{S_i}{A \cdot L}. \tag{2}$$

The area of the engineering zone from Fig.1 can be expressed by the sum of three components:

$$S_i = S_o + S_{ot} + S_{tt}, \tag{3}$$

where S_o, S_{ot} – area of the traces of the transport technological tracks on the main field and on the turning headlands, respectively;

S_{tt} – summary area of the undercarriage traces of the wide span tractor when making a turn.

The area S_o , in agreement with Fig. 1, is equal to:

$$S_o = b_p \cdot [L - 2(K + b_p)] \cdot \left[\frac{A - b_p}{K} + 1 \right], \tag{4}$$

where b_p – width of the transport technological track;
K – track width of the wide span tractor.

We will present the width of the transport technological track b_p by the sum of the widths of the trace b_c from the tires of the wide span tractor and a certain width of technological or steering tolerance c, in particular by the amplitudes of its lateral deviations from the rectilinear movement:

$$b_p = b_c + c \, , \tag{5}$$

In the presented field map (Fig. 1), on each turning headland there are only two transport technological tracks envisaged, which is sufficient both for the pass of the wide span tractor, and its turns. Therefore, the area S_{ot} for two turning headlands will constitute:

$$S_{ot} = 4 \cdot b_p \cdot A. \tag{6}$$

The summary area S_{tt} of the undercarriage traces of the wide span tractor on its turning will constitute:

$$S_{tt} = \pi \cdot b_p \cdot (A - b_p) \tag{7}$$

Results and discussion

After substitution of equations (4), (6) and (7) into (1), considering (5), the coefficient of the loss of the area under the engineering zone w_i will be equal to:

$$w_i = \frac{b_c + c}{L \cdot A} \cdot ([L - 2(K + b_c + c)] \cdot [(A - b_c - c)/K + 1] + 4A + \pi [A - b_c - c]) \tag{8}$$

Analysis of expression (8) confirms the previously mentioned inversely proportional nature of the dependency w_i on the track width K for the wide span tractor. On the contrary, by increasing the width of the tires b_c of the actuators and the technological tolerance c, the losses of the area of the field under the engineering zone increase. Expression (8) has no limiting function w_i from the argument K, yet it allows detection of the point of rational optimal value of the track width, as well as to estimate the impact of the undercarriage parameters of the wide span tractor and the value c of the technological tolerance in the aspect of efficient land use in controlled traffic farming.

For this purpose, using a PC in the Mathcad environment, three curves were built (Fig. 4) of the dependency w_i on K for three tire variants of the wide span tractor standard sizes: 1 – 15.5R38; 2 – 16.9R38; 3 – 15.5R38, with the corresponding widths of the tires: b_{c1} = 0.586 m; b_{c2} = 0.429 m; b_{c3} = 0.393 m.

The range of the factor K in the dependencies presented in Fig.4 can be conditionally divided into two intervals. In each of the intervals the dependency w_i on K is close to the linear one, the function w_i in the interval of the initial values of K decreasing rapidly but for higher values of K – slowly. Let us suppose that to the rational value of K corresponds to an optimum point of the said two-zone curve, which divides the latter into two parts with substantially different properties.

Applying the least square method to determine the parameters of a rational function [19] the points of rational optimum of the two-zone curves were defined in Fig. 4. For the discussed variants of the actuator tire parameters of wide span tractors the rational value of their track width is 7.5 m. The obtained value of the track width of the wide span tractor, using the actuator tires of 0.429 m and 0.393 m, allow having a value of losses of the area under the engineering zone not more than 6 %. But, when the track width K is increased to 9 m, the value of losses of the area is on the level of 5 %.

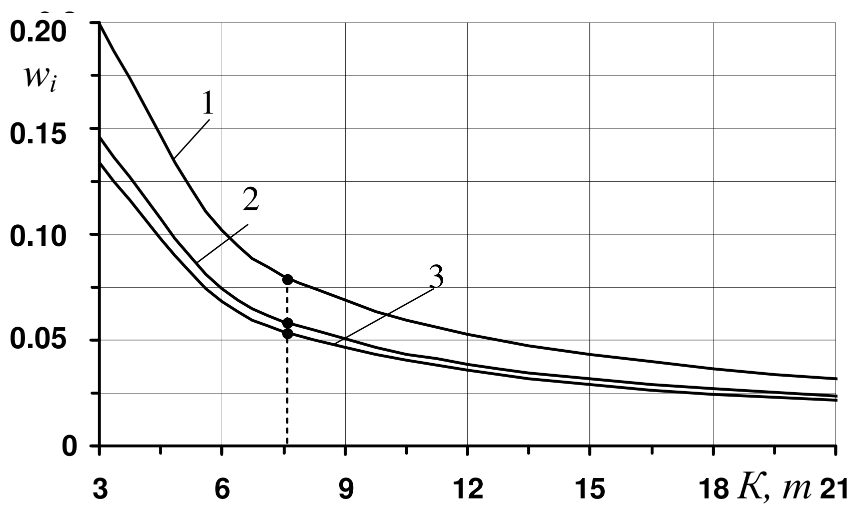

Fig. 4. **Dependency of the coefficient of the losses of area of the field under the engineering zone w_i on the track width K of the wide span tractor depending on the width of the tires of its actuators:** 1 – 0.586 m; 2 – 0.429 m; 3 – 0.393 m

When the wheels of the wide span machine move along a constant technological track and the smaller the width of the tire, the smaller the width of the technological track and, consequently, a smaller field area will be used for the engineering zone, and a larger area will remain on the production zone where the cultivated plants are grown. Here limitations in the minimum tire width are mainly determined by their ability to receive a certain load (carrying capacity). The specified range of tires (0.39-0.45 m) is designed for conventional tractors weighing 4-8 tons, which is enough for this wide span machine.

Let us consider the impact degree of the technological tolerance *c* upon the increase of loss of the field area under the engineering zone w_i. For this, according to equation (8), the dependency w_i on *c* was calculated, the values of which were varied within the range 0...0.3 m (Fig.5).

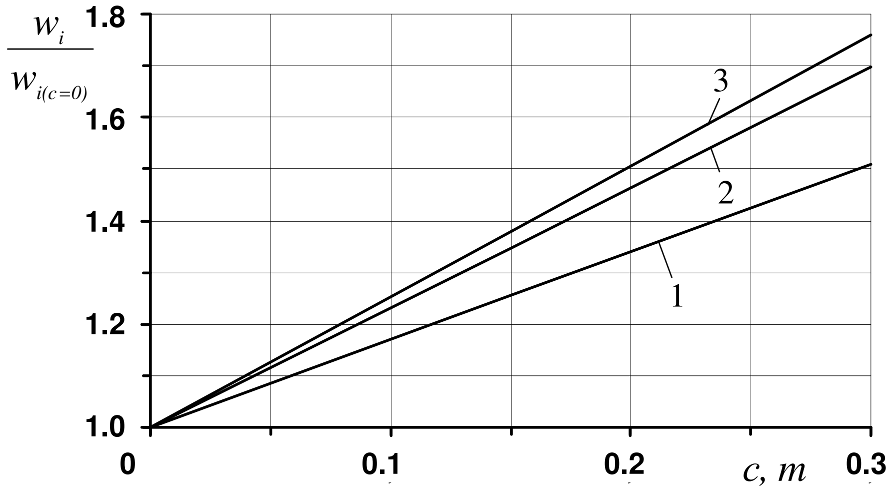

Fig. 5. **Dependence of the width of the technological tolerance c on the increasing rate of losses of the area of the field under the engineering zone $w_i/w_{i(c=0)}$ depending on the width of the actuator tires of a wide span tractor**: 1 – 0.586 m; 2 – 0.429 m; 3 – 0.393 m

It follows from Fig. 5 that the width of the technological tolerance *c* substantially affects the losses of the area of the field under the engineering zone or traffic lane. Increasing the value of *c* to 0.3 m, the area lost to traffic lanes increases by 1.5-1.75 times depending on the tire width variants.

Therefore, the use of a wide span tractor for controlled traffic farming needs justification of the principles of their automatic driving, which will allow maximum increase in the amplitude of lateral deviations from the preset rectilinear path of the travel and, as a consequence, direct reduction in the value *c*. Therefore, automated driving of a wide span tractor can easily be justified because of its ability to reduce lateral driving deviations and, as a consequence, reduce the value of *c*.

Conclusions

The research indicates that planning of the field for controlled traffic farming with the use of a wide span tractor needs to consider its track width as well as other parameters of the vehicle system. The use of wide span tractors with a track width of more than 7.5 m results in 5-6 % loss in area due to tracking, which is quite acceptable. Automated steering of a wide span tractor for controlled traffic farming can easily be justified on the basis of its ability to reduce losses of the field area due to tracking by a factor of up to 1.5.

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