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Theoretical probe of movement of end-effectors wide-track power machines

V. Adamchuk,
Academician of the National Academy of Sciences of Ukraine, Doctor of Technical Sciences
National Science Center "Institute of Mechanization and Electrification of Agriculture"
V. Bulhakov,
Academician of the National Academy of Sciences of Ukraine, Doctor of Technical Sciences
National University of Bioresources and Natural Resources of Ukraine
V. Kuvachov,
Candidate of Technical Sciences
Tavria State Agrotechnological University

The purpose. Elaboration of mathematical dependences determining acceptable limits of cross-section offsets of end-effectors of specialized wide-track agricultural machines, and justifying area of protected zone proceeding from absence of damageability of plants. **Methods.** Original positions of theoretical mechanics, theory of probability, creation of programs and calculations on PC. **Results.** New mathematical dependences determining acceptable limits of cross-section offsets of end-effectors, which are characterized by root-mean-square aberration of agrotechnical conditions according to damageability of plants in a row are developed. Such situation often occurs at general assessment of indexes of operation wide-track agricultural machines in track system of farming agriculture. **Conclusions.** At arrangement of end-effectors of cultivator for wide-track agricultural machines it is necessary to consider the factor of variance of their offsets. For the end-effectors which are outside concerning geometrical axis of a row and center of agricultural machine, the value of protection zone should be greater than for inner, under condition of uniform damage of plants in a row (approximately for 3 cm).

Key words: *track system of farming agriculture, wide-track agricultural machines, damageability of plants, solution on PC.*

The relevance of the question. Damaging plants in the row at cultivation of row crops largely depends on the magnitude of lateral displacement of the working tools and the magnitude of the protective zone of the row. No doubt that the spread of the plants in the row is also reflected in the extent of their damage.

Transverse displacement of the working tools largely depend on the stability of motion of the agricultural unit, which is the result of many factors: the uneven resistance of the soil, the type of propulsion and its moment of resistance to rotation, speed of movement, force etc.

The research and study of the stability of motion wide span tractors (vehicles) designed for the track and the pavement of farming systems [1-4] is a subject of special attention. In particular, and because the course angle deviation leads to a significant displacement of the working tools, especially the extreme. And, depending on the size of the protective zone directly affects the damageability of plants in the row.

Analysis of recent researches and publications. The study of the stability of motion wide span tractors (vehicles) is the subject of a special study, is adequately considered in [5-8] and therefore, in this work not considered. The task consists in establishing mathematical relationships allowing to determine the quantitative effect of lateral displacement of the working tools and the value of the protection zone for damdddd bbbaging plants in the row due to the direct cutting of their working tools.

The purpose of the research. Development of mathematical dependences allowing to define the permissible limits of lateral displacement of the working tools of the wide span tractors (vehicles) and justify the value of the protective zone, while the absence of damage to plants.

The methodology of research. The basis of theoretical studies based on the main provisions of theoretical mechanics, probability theory, programming and calculations on a PC.

The results of the research.

Consider the main factors, from a kinematic point of view, affecting the lateral offset, taken separately working on wide span tractors (vehicles), which follows the steps of permanent tramlines (Fig. 1).

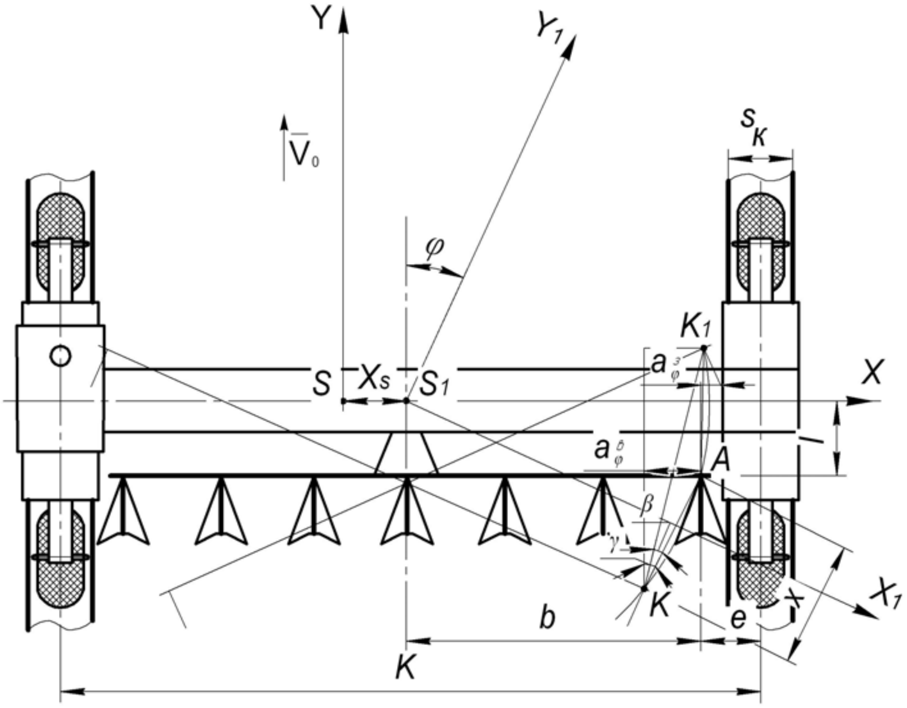

Fig. 1 – Scheme of the lateral displacement wide span tractors (vehicles) and its working tools

Fig. 1 it is not difficult to imagine that the total displacement taken separately working on the sum of the displacement X_S of the center wide span tractors (vehicles) (*S*) from the set direction of movement and the displacement due to angular deviation.

The shift of the wide span tractors (vehicles) occurs as a result of the simultaneous action of many independent variables [6-8], and therefore probably agrees with normal distribution. Although this fact requires experimental confirmation, but at this stage of research will make this assumption. Transverse displacement of the working tools due to angular rotations wide span tractors (vehicles) depend on the size of the latter, which change all the time, and the parameters characterizing their placement. And as we know from probability theory, the total set of independent variables acting in the course of one of prevloua processes can lead to inconsistency of the law of normal distribution. Such case occurs when the transverse displacement of the working tool, where the permanent factor on the process is a parameter that characterizes its placement in the unit.

Projimo that curves *1* and *2* (Fig. 2) characterize the density probability of displacements, taken separately working on wide span tractors (vehicles) from a given direction of motion Y_t-Y_t and placement of plants relative to the axis line Y_r-Y_r. The segment *Z* is the area of possible location of the working tool with some probability $p(X_{tZ})$ and finding the plants with a probability $p(X_{rZ})$.

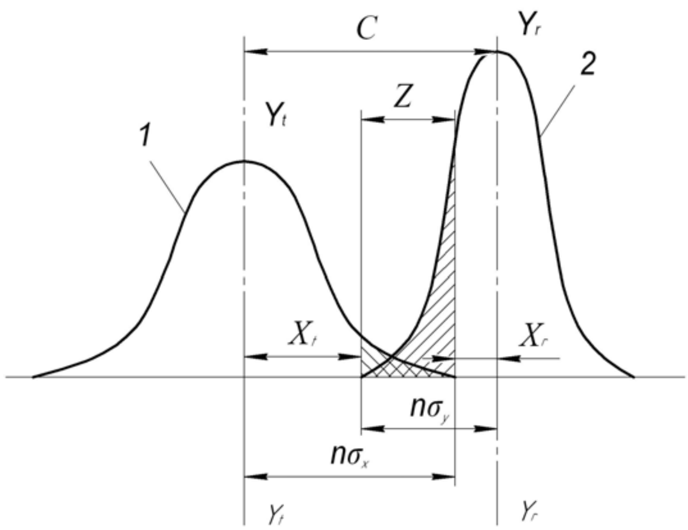

Fig. 2 – Scheme of the probability density of the displacement of the working tool from a predetermined direction 1 and the location of the plants relative to the axis row 2

Then the probability of plant damage $p(D_Z)$ in the zone *Z* may be determined on the basis of multiplication theorem of probability [9]:

$$p(D_z) = p(X_{tZ} \cdot X_{rZ}) = p(X_{tZ}) \cdot p(X_{rZ}). \quad (1)$$

If the protective zone *C* is large enough so that curves *1* and *2* (Fig. 2) do not intersect, then area *Z* is absent and damage to the plants due to pruning work on will not. From Fig. 2 find the value boundaries for X_{1t} and X_{1r} zone *Z*:

$$\begin{aligned} X_{1t} &= C - n\sigma_{Xr}, \\ X_{1r} &= C - n\sigma_{Xt}, \end{aligned} \quad (2)$$

where σ_{Xt} and σ_{Xr} – the standard deviation of the working tool and placement of plants;

$n\sigma_{Xt}$ and $n\sigma_{Xr}$ – the variance limits, in which with sufficient accuracy the value of n may be taken equal to 3;

C – the value of the protection zone.

The probability of finding work on $p(X_{tZ})$ in the zone Z in the General form can be expressed through the function of placing the $F(n\sigma_{Xt})$ and $F(X_{1t})$ and the probability density [10]:

$$p(X_{tZ}) = p(X_{1t} \langle X_{tZ} \langle n\sigma_{Xt}) = F(n\sigma_{Xt}) - F(X_{1t}) = \int_{-\infty}^{n\sigma_{Xt}} f(X_t)dx - \int_{-\infty}^{X_{1t}} f(X_t)dx. \quad (3)$$

Similarly, we represent the probability of placement of plants $p(X_{rZ})$ in the same area:

$$p(X_{rZ}) = p(-n\sigma_{Xr} \langle -X_{rZ} \langle -X_{1r}) = F(-X_{1r}) - F(-n\sigma_{Xr}) = \int_{-\infty}^{X_{1r}} f(X_r)dx - \int_{-\infty}^{n\sigma_{Xr}} f(X_r)dx. \quad (4)$$

Substituting (3) and (4) in (1) and taking into account expression (2) will receive a probability of damage of plants, expressed through the probability density of the deviation of the working tool and the location of the plants:

$$p(D_z) = \left[\int_{-\infty}^{n\sigma_{Xt}} f(X_t)dx - \int_{-\infty}^{C-n\sigma_{Xr}} f(X_t)dx\right] \cdot \left[\int_{-\infty}^{-(C-n\sigma_{Xt})} f(X_r)dx - \int_{-\infty}^{-n\sigma_{Xr}} f(X_r)dx\right]. \quad (5)$$

Under normal law placement using the known dependence of the normalized probability density [10] and introducing the legend of the integral functions of the equation (5) takes the form:

$$p(D_z) = \left[F(n)_{Xt} - F\left(\frac{C - n\sigma_{Xr}}{\sigma_{Xt}}\right)\right] \cdot \left[F(n)_{Xr} - F\left(\frac{C - n\sigma_{Xt}}{\sigma_{Xr}}\right)\right], \quad (6)$$

$$F(n)_{Xt} = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{n} e^{-\frac{t_{Xt}^2}{2}} dt_{Xt},$$

$$F(n)_{Xr} = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{n} e^{-\frac{t_{Xr}^2}{2}} dt_{Xr},$$

де $F\left(\frac{C - n\sigma_{Xr}}{\sigma_{Xt}}\right) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\frac{C-n\sigma_{Xr}}{\sigma_{Xt}}} e^{-\frac{t_{Xt}^2}{2}} dt_{Xt},$

$$F\left(\frac{C - n\sigma_{Xt}}{\sigma_{Xr}}\right) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{\frac{C-n\sigma_{Xt}}{\sigma_{Xr}}} e^{-\frac{t_{Xr}^2}{2}} dt_{Xr},$$

$$t_{Xt} = \frac{X_t}{\sigma_{Xt}};\ dt_{Xt} = \frac{dx_t}{\sigma_{Xt}};\ t_{Xt} = \frac{X_r}{\sigma_{Xr}};\ dt_{Xr} = \frac{dx_r}{\sigma_{Xr}}.$$

Equation (6) is true for assumptions, according to which the distribution of displacements of the working tools and placing the plants in a row in good agreement with the normal law (Laplace-Gauss). However, due to the fact that traditional tractor units "external" and "internal" offset of the same working tool are unequal to each other at identical angular oppositely directed deviations of the tractor [11], and for the wide span tractors (vehicles) should probably expect the same result. The latter can not affect the nature of the distribution of the totality of the lateral displacement of the working tool of the wide span tractors (vehicles).

Fig. 1 find that cremation "internal" displacement of the working tool due to angular deviation wide span tractors (vehicles) on the angle *φ*, is equal to:

$$a_{\phi}^{в} = x\sin(\gamma + \beta) = x(\sin\gamma \cdot \cos\beta + \cos\gamma \cdot \sin\beta)\,, \tag{7}$$

where $x=KA=AK_1$ – the deviation of the working tool;

γ – the angle-dependent design parameters wide span tractors (vehicles) (*b*, *l*);

β – angle, depending on the magnitude of angular deviation wide span tractors (vehicles) *φ.*

Similarly, for external displacement of the working tool:

$$\alpha_{\phi}^{з} = x\cos(\gamma + \beta) = x(\cos\gamma \cdot \cos\beta - \sin\gamma \cdot \sin\beta)\,. \tag{8}$$

Expressing the values of the right-hand side of equations (7) and (8) through the structural parameters *b* and *l* of the wide span tractors (vehicles), as well as the course angle *φ*, we obtain the following dependences of the transverse displacements of the working tool:

$$\begin{aligned} \alpha_{\phi}^{в} &= l\sin\phi + b(1\text{-}\cos\phi); \\ \alpha_{\phi}^{з} &= l\sin\phi - b(1\text{-}\cos\phi), \end{aligned} \tag{9}$$

where *b* and *l* – respectively, the distance from the longitudinal and transverse axis of the wide span tractors (vehicles) passing through its center to the working tool.

For the extreme working tool, the constructive parameter *b* in the dependences (9) is proportional to the width of the wide span tractors (vehicles), which, in Fig. 2 can be represented as follows:

$$2b_к = K\text{-}2e\,, \tag{10}$$

where $b_к$ – the distance from the longitudinal axis of the wide span tractors (vehicles) passing through its center to the extreme working tool;

K – size of the track wide span tractors (vehicles);

e – technological zone.

Let's assume that the technological zone is for Fig. 2 is defined by the width of the technological path s_k and the value of the protective zone *C*:

$$e = 0{,}5s_к + C\,. \tag{11}$$

Taking into account the dependences (10) and (11) of the equation (9), the transverse displacements for the extreme working tool will take the form:

$$\begin{aligned} \alpha_{\phi}^{в} &= l\sin\phi + (0{,}5K - 0{,}5s_к - C)(1\text{-}\cos\phi); \\ \alpha_{\phi}^{з} &= l\sin\phi - (0{,}5K - 0{,}5s_к - C)(1\text{-}\cos\phi). \end{aligned} \tag{12}$$

As can be seen from the obtained equations (12), the internal and external displacement of the working tools are not equal among themselves ($\alpha_\phi^в \neq \alpha_\phi^з$) at the same angular deviation of the agro means by the value of *φ*. On the magnitude of the quantitative change in the internal $\alpha_\phi^в$ and external $\alpha_\phi^з$ displacement of the extreme working organ, depending on the angular deviation *φ* of the wide span tractors (vehicles) at a different value of its track *K*, one can observe in Fig. 3

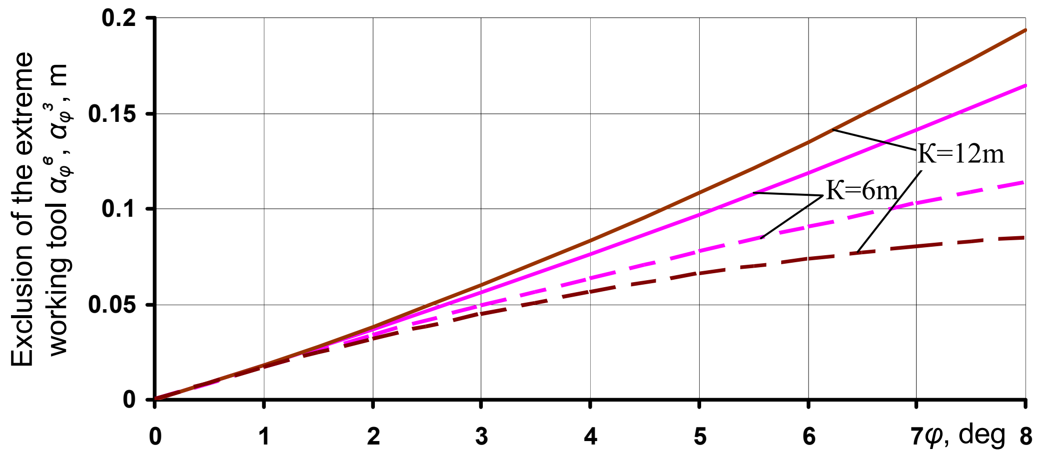

Fig. 3 - Internal $\alpha_\phi^в$ (——) and external $\alpha_\phi^з$ (–––) displacement of the extreme working tool, depending on the angle deviation φ of the wide span tractors (vehicles) at different values of its track K

As we see from Fig. 3, the difference in the displacements of the extreme working tools increases with the increase of the track *K* of the wide span tractors (vehicles) and the angle of deviation *φ*. For small values of these parameters, the difference in displacement is negligible. Therefore, for wide span tractors (vehicles) should take into account the factor of the difference of displacements of working tools (especially extreme), which affects the asymmetry of distribution.

Consequently, if the individual displacements of the working tool from a given direction of movement to the opposite sides are unequal with each other, then their aggregate will also not be equal. In this, it is not difficult to make sure if in the right side of the equations (9), instead of the unit value of the angle *φ*, we set the value of the mean square angular deviation of the wide span tractors (vehicles). In this case, we obtain the mean square displacement of the working tool, which corresponds to the mean square angular deviation of the wide span tractors (vehicles).

The application of simple change of unit (random) values of values to the mean-square deviation within the limits of small values of the angles *φ* is quite permissible. Because these equations represent a linear function under this condition and it is not necessary to resort to its linearization.

Taking into account the above equation (12) will have the form:

$$\sigma_{\alpha_\phi^в} = l \sin\sigma_\phi + b\left(1 - \cos\sigma_\phi\right);$$
$$\sigma_{\alpha_\phi^з} = l \sin\sigma_\phi - b\left(1 - \cos\sigma_\phi\right), \qquad (13)$$

where $\sigma_{\alpha_\phi^в}, \sigma_{\alpha_\phi^з}$ - mean-square deviation deviation of internal and external bias of the working tool due to angular deviations of the wide span tractors (vehicles);

σ_ϕ - mean-square deviation, which characterizes the set of all angular deviations of wide span tractors (vehicles) from a given direction of motion.

Because the displacement of the working tool due to the angular deviations of the wide span tractors (vehicles) is an integral part of the general displacements, the latter are also not equal with each other in the case of opposing variations of the aggregate:

$$\sigma_{\alpha_\phi^в} - \sigma_{\alpha_\phi^з} = 2b\left(1 - \cos\sigma_\phi\right). \qquad (14)$$

Consider the damage to plants, taking into account the asymmetric distribution of the displacements of the working tools.

Let curves 1 and 3 (Fig. 4) characterize the density of the asymmetric distribution of the probability of transverse displacements of the working tools placed on both sides of the line, and curve 2 - the placement of plants. Obviously, the probability of the appearance of the left working tool in the Z_n zone is not equal to the probability of the appearance of the right working tool in the Z_n region (the area of the shaded sections of the Z_n and Z_n of the segments 1 and 3 is uneven), that is,

Let's consider the damage of plants taking into account indicators of asymmetry of distribution of displacements of working tool:

$$p\left(X_{tZn}\right) \neq p\left(X_{tZn}\right). \tag{15}$$

Similarly, for placement of plants:

$$p\left(X_{rZn}\right) \neq p\left(X_{rZn}\right). \tag{16}$$

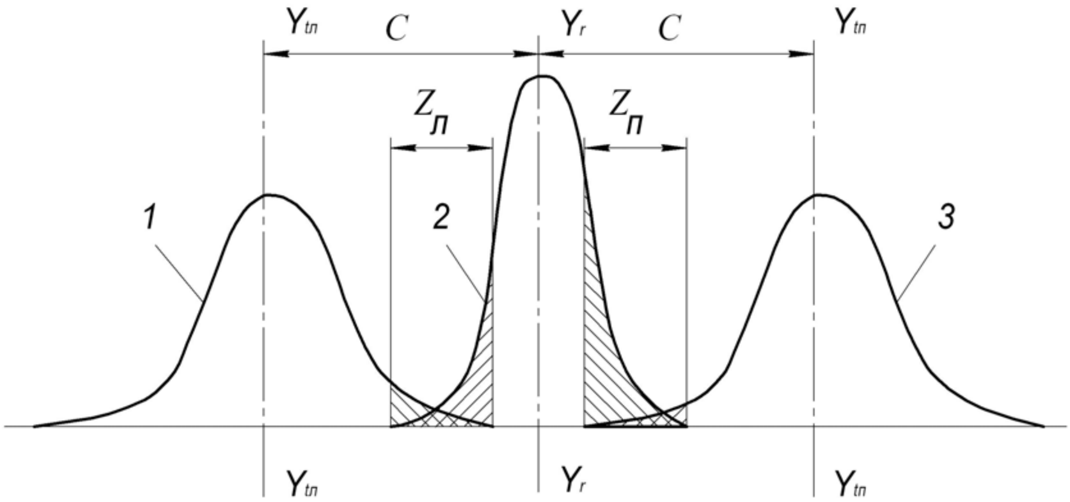

Fig. 4 – Scheme of the density of asymmetric distribution of the probability of displacements of the left 1 and right 3 working tools on both sides of the line from the given direction of movement and placement of plants 2

The damage to plants for the left and right working tool in general is determined:

$$\begin{aligned} p\left(D_{Zn}\right) &= p\left(X_{tZn} \cdot X_{rZn}\right) = p\left(X_{tZn}\right) \cdot p\left(X_{rZn}\right); \\ p\left(D_{Zn}\right) &= p\left(X_{tZn} \cdot X_{rZn}\right) = p\left(X_{tZn}\right) \cdot p\left(X_{rZn}\right). \end{aligned} \tag{17}$$

Because the right-hand sides of the equations (17) are not equal to each other, then $p\left(D_{Zn}\right) \neq p\left(D_{Zn}\right)$. In this way, we conclude that the damage to the plants due to trimming at the same protective zone *C* for the left and right working tool is different. The difference in the damage is increased with an increase in the asymmetry of the distribution curves of the displacements of the working organs and plants.

In order to determine the probability of damage to plants in this case, it is expedient to use a distribution law that takes into account the excess and the asymmetry of distribution [10]. The density function for a given distribution is expressed with a sufficient degree of accuracy by the equation [10]:

$$f_A\left(X\right) = f\left(X\right) - \frac{r_3}{6} f^{(2)}\left(X\right) + \frac{r_4 - 3}{24} f^{(3)}\left(X\right), \tag{18}$$

where *f(X)* – normal distribution density function;

$f^{(i)}(X)$ – derivatives of a normal distribution density function;

r_3, r_4 – highlights.

Then, similarly to equation (6), the probability of damage to plants by the left and right working tools relative to the line axis will be determined normal distribution density function:

$$p_A\left(D_{Zn}\right)=\left\{\begin{array}{l}\left[F\left(n\right)_{Xt}-\frac{r_3}{6}f^{(2)}\left(n\right)_{Xt}+\frac{r_4-3}{24}f^{(3)}\left(n\right)_{Xt}\right]-\\-\left[F\left(\frac{C-n\sigma_{Xr}}{\sigma_{Xt}}\right)-\frac{r_3}{6}f^{(2)}\left(\frac{C-n\sigma_{Xr}}{\sigma_{Xt}}\right)+\frac{r_4-3}{24}f^{(3)}\left(\frac{C-n\sigma_{Xr}}{\sigma_{Xt}}\right)\right]\end{array}\right\}\cdot$$
$$\cdot\left\{\begin{array}{l}\left[F\left(-\frac{C-n\sigma_{Xt}}{\sigma_{Xr}}\right)-\frac{r_3}{6}f^{(2)}\left(-\frac{C-n\sigma_{Xt}}{\sigma_{Xr}}\right)+\frac{r_4-3}{24}f^{(3)}\left(-\frac{C-n\sigma_{Xt}}{\sigma_{Xr}}\right)\right]-\\-\left[F\left(-n\right)_{Xt}-\frac{r_3}{6}f^{(2)}\left(-n\right)_{Xt}+\frac{r_4-3}{24}f^{(3)}\left(-n\right)_{Xt}\right]\end{array}\right\}. \quad (19)$$

$$p_A\left(D_{Zn}\right)=\left\{\begin{array}{l}\left[F\left(-\frac{C-n\sigma_{Xr}}{\sigma_{Xt}}\right)-\frac{r_3}{6}f^{(2)}\left(-\frac{C-n\sigma_{Xr}}{\sigma_{Xt}}\right)+\frac{r_4-3}{24}f^{(3)}\left(-\frac{C-n\sigma_{Xr}}{\sigma_{Xt}}\right)\right]-\\-\left[F\left(-n\right)_{Xt}-\frac{r_3}{6}f^{(2)}\left(-n\right)_{Xt}+\frac{r_4-3}{24}f^{(3)}\left(-n\right)_{Xt}\right]\end{array}\right\}\cdot$$
$$\cdot\left\{\begin{array}{l}\left[F\left(n\right)_{Xt}-\frac{r_3}{6}f^{(2)}\left(n\right)_{Xt}+\frac{r_4-3}{24}f^{(3)}\left(n\right)_{Xt}\right]-\\-\left[F\left(\frac{C-n\sigma_{Xt}}{\sigma_{Xr}}\right)-\frac{r_3}{6}f^{(2)}\left(\frac{C-n\sigma_{Xt}}{\sigma_{Xr}}\right)+\frac{r_4-3}{24}f^{(3)}\left(\frac{C-n\sigma_{Xt}}{\sigma_{Xr}}\right)\right]\end{array}\right\}. \quad (20)$$

To investigate the probability of damage to plants from the magnitude of the protective zone of the line, assume that the mean square deviations of the displacements of the working tools of the wide span tractors (vehicles) and the placement of plants relative to the line axis are approximately equal to $\sigma_{Xt}=\sigma_{Xr}$. This assumption is quite feasible if the desired structural and technological parameters and other parameters of the wide span tractors (vehicles) and its high level of automation of driving provides acceptable stability and controllability of movement, as it follows from the analysis of the research described in [5-8].

The result of the calculation of the probability of damage to plants with a wide span tractors (vehicles) with a width of the track K = 12 m from the value of the protective zone of the line is presented in Fig. 5. From the above graph, it follows that with the same value of the protective zone, the damage to the plants by the working tool, located outside the geometric axis of the line and center of the wide span tractors (vehicles) (curve 2), and inside (curve 1) is different. For example, in a protective zone of 13 cm, the probability of damage to the external working tool is 5.5%, internal - 1%. The difference, as we see, in the damage to plants is significant.

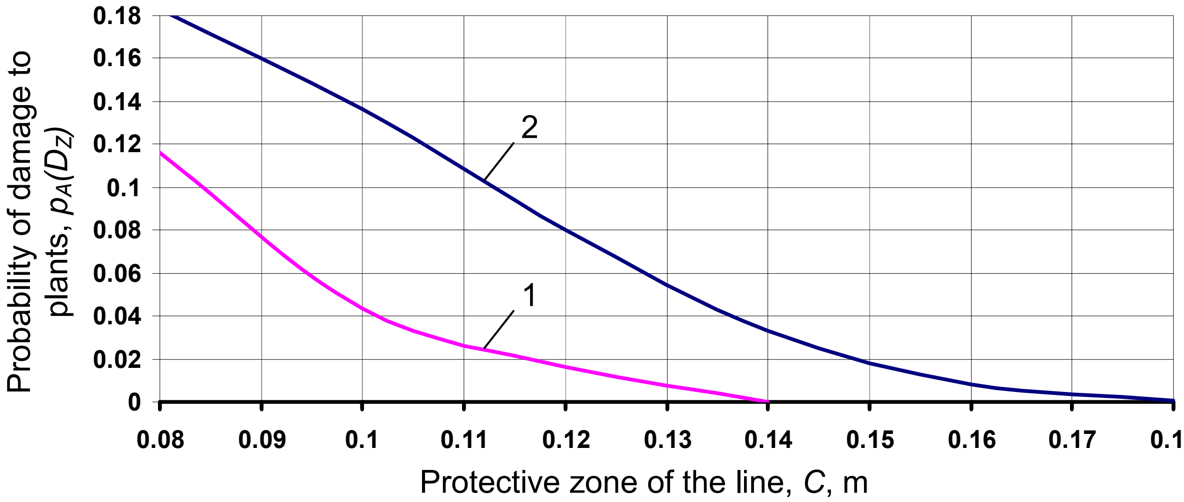

Fig. 5 - Probability of damage to plants depending on the size of the protective zone C: 1 - the internal working tool; 2 - external working tool

On the basis of the above, we can conclude that both working tools of a wide span tractors (vehicles), which are on both sides of the line, should be placed at a different distance from the axis of the line. In our case, in case of damage to plants up to 1%, the protective zone of the rows treated by the extreme working tools should be 13 and 16 cm respectively.

Conclusions

The proposed method for determining the probability of damage to plants in a row allows reasonably to choose the size of the protective zone, taking into account the structural parameters of wide span tractors (vehicles) intended for the agricultural system, as well as their stability and controllability of movement. When placing cultivator working tools for a wide span tractors (vehicles) should take into account the factor of difference between their displacements. For working tools located outside with respect to the geometric axis of the line and the center of the means, the size of the protective zone should be greater than for the internal ones, provided that the plants are evenly damaged in a row (approximately 3 cm).

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