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PROBABILISTIC CHARACTERISTICS OF PROCESSES IN MODELS OF THE OPERATION OF ROW CROP CULTIVATOR AGGREGATES

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Abstract

The main agrotechnical requirements for cultivators working between rows are as follows: uniform of rows loosening between rows (stability of depth of loosening), complete destruction of weeds in spacings and rows, absence of damage to cultivated plants in rows and falling asleep with their soil (keeping the width of the protective zone). The highest quality of work will be if the trace of the last to the row of the working body copies the line of the row. The article presents a model for processing information when performing a cultivator technological process, presents the results of the probabilistic characteristics of the processes in the functioning models of cultivating aggregates.

The experiment was conducted on a cultivator model. The model is equipped with tracering devices instead of the working bodies of the cultivator. Using the model, it is possible to imitate the technological process of intertillage "inter-row of cultivated plants" on the coordinate sheet. The movement of the model is carried out in such a way that the line drawn by the cultivator tracer (trajectory of the working body) is equidistant to the line of the row of plants.

The width of the protective zone consists of two parts: the width of the root protective zone and the width of the additional protective zone. The width of the additional protective zone depends on the size of the inevitable deviation from the line of the row of plants during the movement of the working body in the spacings. The deviation from the width of the additional protective zone is equal to the deviation from the width of the permissible protective zone of the working body when the cultivator moves. Since the value of the width of the root protective zone does not change during a certain growing period. This indicates that the deviation from the width of the additional protection zone can be measured by the deviation from the width of the protective zone.

The change in the additional protective zone is affected by the straightness of the rows of plants, the kinematic parameters of the cultivator, soil properties, furrow profile, tractor driver skills and much more.

It is well known from probability theory that the sum of many random variables approximately obeys the law of normal distribution, even if these values are little interconnected. Thus, for acceptance or rejection of reliability, the initial hypothesis that the deviation of the additional protective zone obeys the law of normal distribution can be selected and verified by the Pearson criterion.

Based on the statistics of processes when working on inter-row cultivation of row crops, it is possible to construct graphs of normalized spectral densities of the width of the protective zone and analyze the probability of damage to plants. Based on the statistical series of deviations of the width of the protective zone compiled during the study, a histogram of the distribution of deviations of the width of the protective zone and a graph of the theoretical distribution density are constructed.

The permissible number of damaged plants is a prerequisite for the creation of additional protective zones. The working body of the cultivator should be located at such a distance from the plant so that the probability of approaching the value of the width of the root zone does not exceed the value of the standard deviation. For this, it is necessary that the value of the normal distribution function be equal to the standard deviation.

Based on the results obtained during experiments with a cultivator model, the hypothesis is confirmed or refuted. If this is confirmed, an acceptable value for the width of the protection zone is presented. Therefore, based on these studies, it is possible to determine the width of the protective zone by inter-tilling of row crops.

Key words: *cultivator aggregate model, protective zone, agrotechnical assessment, tests, plant lines.*

The quality of the cultivator's work when cultivating the soil in row-spacings is the uniformity of the depth of cultivation $a(t)$ and the consistency of the width of the protective zone $l\ (t)$. The highest quality of work will be in the event that the trace $y_{kl}(t)$ of the utmost to row working body (chisel) copies the row line $y_p(t)$. The error $\varepsilon\ (t)$ between the established (adjusted) boundary of the protective zone $y_o(t)$ and the path $y_{kl}(t)$ of the utmost working body (chisel) determines the deviation of the actual width of the protective zone $l(t)$ from the given value l_o, and $l(t) = y_{kl}(t) - y_p(t)$. In the calculated scheme for analyzing the output process $l(t)$, the aggregate can be represented as a series connection of four links. In this case, the output signal for the first link (driver) will be the turn of the steering wheel $\varphi_P(t)$, for the second link (steering mechanism) - the turn of the steering wheels $\varphi_k(t)$, for the third link (tractor) - the turn of the longitudinal axis of the tractor $\varphi_t\,(t)$. As a result of this turn, the longitudinal axis of the cultivator will also be turned by a certain angle, which determines the corresponding width $l(t)$ of the protective zone.

When cultivating irrigated crops, row-spacing is carried out using a cultivator that scratches the soil, removes weeds and cuts irrigation furrows. In order to avoid damage to the plants in rows, the edges of the cultivator's working bodies are placed at the width of the protective zone L, on the first cultivation, at L = 8 ... 12 cm, on subsequent L = 14 ... 15 cm [1].

The protection zone consists of two parts (Figure 1):

$$L=l_0+l, \tag{1}$$

where l_0 is the value of the root part, mm,

l is the value of the additional protective zone, mm

The root zone l_0 is a quantity that depends on the structure and size of the crop root and soil properties.

The value of the additional protective zone (l) depends of the size of the inevitable deviation from the equidistant movement of the working body in the row-spacings during cultivation. The error (ΔL_i) of the value of the protective zone (L) is equal to the error caused by the inevitable deviation of the working body of the cultivator (ΔL_i) during movement, $\Delta l_i = \Delta L_i$. Because at a certain period in the development of culture l_0 = const. This indicates that the error of the additional protection zone (l) can be determined by the error of the protective zone (L) (l).

There are various reasons why the additional protection zone (l) changes. For example, the correctness of the rows of plants, the kinematic parameters of the cultivating aggregate, the properties of the soil, the profile of the furrow, the skills of a tractor driver and much more.

From probability theory, we know that a sufficiently large set of random values obeys the law of normal distribution, even if these values are not interrelated, [1-3].

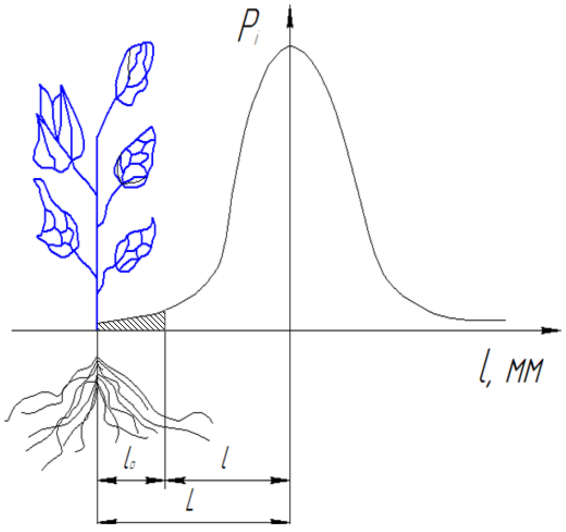

Fig.1. Scheme for calculation the width of the protective zone

From the above, one can choose the initial hypothesis that the error of the additional protective zone (Δl_i) obeys the law of normal distribution. The law of normal distribution has the following probability densities:

$$P_i = \frac{1}{\sigma\sqrt{2\pi}} e^{-\frac{1}{2}\left(\frac{l_i-\bar{l}_i}{\sigma}\right)} \tag{2}$$

where σ is the root-mean-square deviation;

$\bar{l}_i$ is the arithmetic mean deviation;

l_i is the corresponding size of the protective zone.

The arithmetic mean deviation from the values of the protective zone is determined as follows:

$$\bar{l}_i = \frac{\sum_{i=1}^{n} l_i}{n} \tag{3}$$

where n is the number of measurements.

The root-mean-square deviation is calculated by the following formula:

$$\sigma = \sqrt{\frac{(\Delta l_1)^2 m_1 + (\Delta l_2)^2 m_2 + \dots + (\Delta l_i)^2 m_i}{n}}\ , \tag{4}$$

where $\Delta l_i = l_i - \bar{l}_i$ is the number of measurements in intervals.

With multiple measurements (100 or more), a statistical line is compiled. To do this, the entire error range (Δl_i) is divided into intervals and the number of measured values (m_i) for each i-interval is calculated. The frequency for each interval is determined from the expression.

$$P^* = \frac{m_i}{n} \tag{5}$$

For a graphical representation of the statistical line, a histogram is compiled. To construct a histogram on the abscissa axis, the width of the interval is laid aside and regular rectangles are plot. In order to find the correct rectangle height, it is necessary to divide the frequency (P_i) for each interval by its width (group size). As a result, the surface area of the rectangle of each group is equal to the frequency of this group, and the sum of the surface areas of all the rectangles is unity.

To accept or reject the selected hypothesis that the error of the protective zone obeys the law of normal distribution, the correspondence of the theoretical and statistical distributions is checked using χ^2 (Pearson criterion).

Correspondence is calculated using the following formula:

$$\chi^2 = \sum_{i=1}^{k} \frac{(m_i - nP_i^*)^2}{nP_i} \qquad (6)$$

where k is the number of groups;

P_i - is determined from formula (2)

The correspondence of the values (χ^2) is also a random variable, its distribution is related to the quantity *(r)*, which is called the "degree of freedom" of the distribution

$$r = R - S \qquad (7)$$

where S is the number of freedom conditions specified for the frequency $P*$.

In this case, the following three conditions are required, (S = 3):

a) $\sum_{i=1}^{k} P_i^* = 1$; the sum of the frequencies is equal to one. This condition is always established.

b) $\sum_{i=1}^{k} l_i P_i^* = \bar{l}_i$ the theoretical distribution should be chosen so that the arithmetic mean of the statistical expectation and statistical deviation is equal.

c) $\sum_{i=1}^{k} (l_i - \bar{l}_i) P_i^* = D$ condition for the correspondence of theoretical and statistical variances;

R is the probability that the value of the compliance indicator for random reasons is not less than the value calculated by the experiment (6).

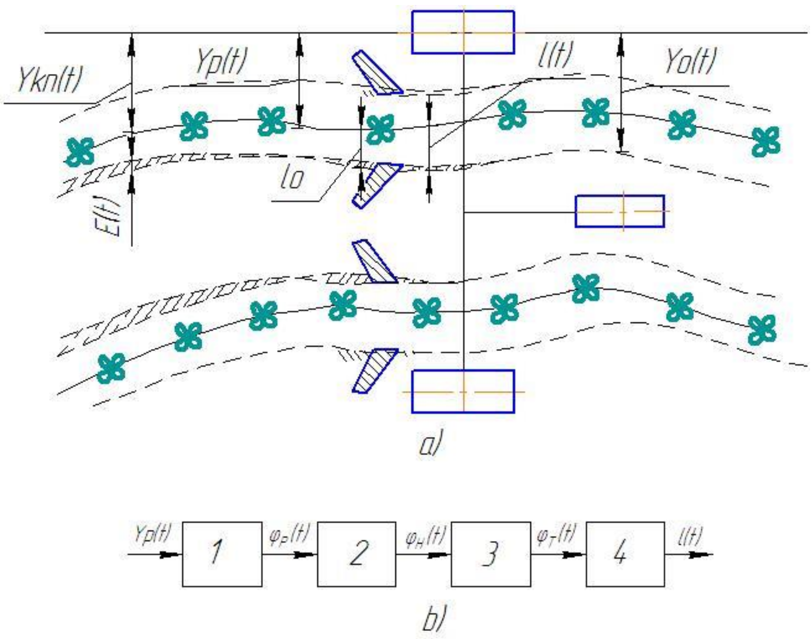

Fig.2. The trajectory of the points of the cultivator working bodies *(a)*, the information processing model *Yp (t) (b).*

The experiments were carried out using a model of a cultivator aggregate. To do this, lines of rows of plants are randomly applied on graph paper. Plant row lines may consist of periodic curves. The cultivator model is equipped with writing devices installed in the places of attachment of the working bodies. Thus, the process of row-spacing tilling by the cultivator aggregate is simulated. The model is manually guided between the rows. And the lines that are drawn by the working bodies (trajectories of movement) make equidistant movements along the row-spacings. The protection zone is measured after 10 mm. Measurements are taken to the right or left of the row (Fig. 2). The measurement results are recorded in Table 1.

Table. 1.

Deviation of the working bodies of cultivator aggregate model from the protective zone during row spacing

№	Results of experiment, mm	№	Results of experiment, mm	№	Results of experiment, mm
1	11	11	7	21	10
2	10	12	7	22	12
3	9	13	9	23	11
4	8	14	10	24	12
5	9	15	11	25	11
6	10	16	9	26	10
7	11	17	8	27	10
8	12	18	8	28	12
9	11	19	9	29	10
10	8	20	8	30	9

Using the above results, as well as formulas (2), (3), (4), (5) and (6), we find the statistical series of deviations from the protective zone. In the calculations, the Excel program was used, the obtained data are presented in Table 2

Table. 2.

The statistical series of deviations from the protective zone

T/r	Interval, mm	Групповая ошибка Group error mm	Setting measurement results by groups	Number of measurements in groups m_i	Theoretical density *P(Δl)*	Frequency $P^*(\Delta l)$
1	7-8	7	*II*	2	0.0279471	0.07
2	8-9	8	*IIIII*	5	0.1206945	0.17
3	9-10	9	*IIIIII*	6	0.2707402	0.20
4	10-11	10	*IIIIIII*	7	0.3154516	0.23
5	11-12	11	*IIIIII*	6	0.1909094	0.20
6	12-13	12	*IIII*	4	0.0600118	0.13

If the probability *P* is very small, that is, the value of the degree of compliance is actually less than the experimental result for random reasons, the experimental results contradict our hypothesis. In this case, the selected normal distribution is rejected, and based on the results of the experiment, the new distribution law (new hypothesis) is again checked by the criterion χ^2 [4-6].

If the error of the working body of the cultivator (Δl_i) is really true to the distribution law, the probability P is relatively high (usually $P > 0.1$). In this case, the difference between the theoretical and statistical distribution is considered partial and due to random reasons. In this case, the value of the protective zone will be determined so that the probability of damage to the plant does not exceed the permissible limits.

Based on the statistical series of deviations from the protective zone, we construct a histogram of the distribution of the protective zone (Figure 3) and a graph of the theoretical density distribution of the width of the protective zone (Figure 4).

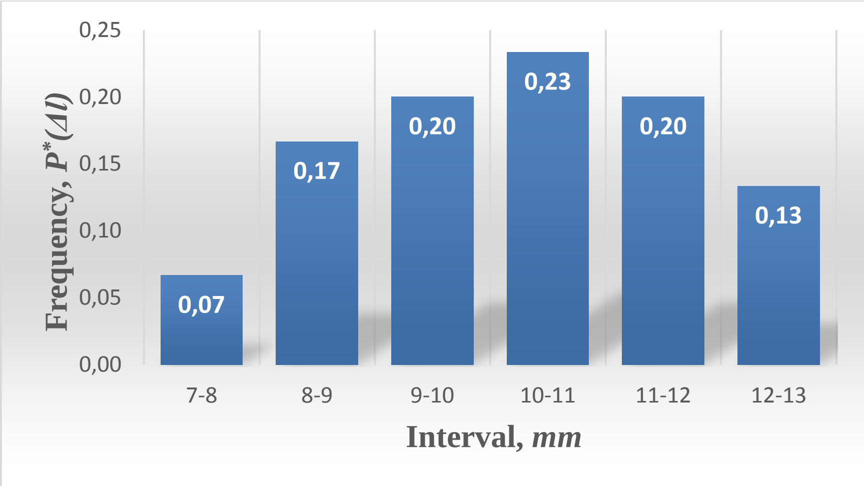

Fig.3. The histogram of the distribution of deviation of the protective zone's width

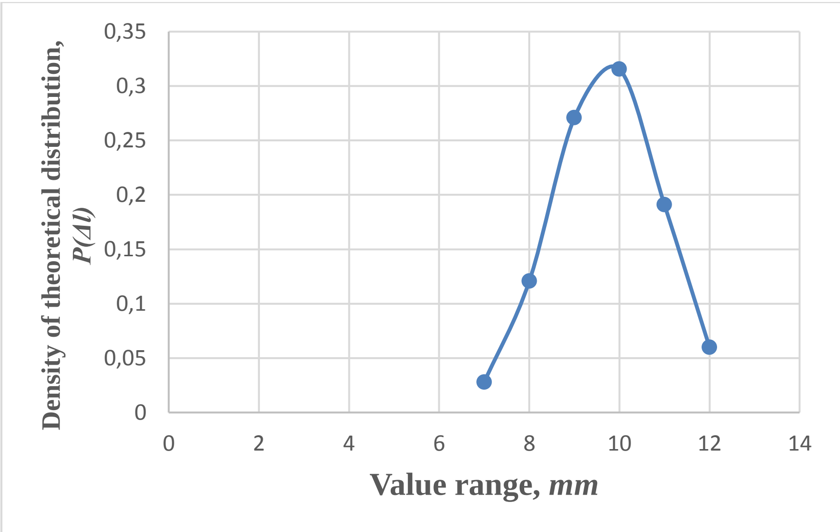

Fig.4. The graph of the theoretical distribution density of the protective zone's of the width

The permissible amount of plants damage is a prerequisite for the creation of additional protective zones. In order for the condition to be fulfilled, the probability of plant damage should not exceed δ. The working body of the cultivator should be located at a distance *(L)* from the plant, so that its probability of approaching to plant at a distance greater than l_0 does not exceed δ. For this, it is necessary to ensure that the value of the normal distribution function $F\ (l_i)$ is equal to δ:

$$\delta = F(l_i) = \frac{1}{\sigma\sqrt{2\pi}} \int_{-\infty}^{l} e^{-\frac{(l_i-\bar{l})}{2\sigma^2}} dl_i$$

This integral is not represented by an elementary function; therefore, it is calculated by converting into a function the probability integral.

Probability integral

$$\delta = \mathrm{F}^*(l) = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{l} e^{-\frac{t^2}{2}} dt$$

When changing a variable

$$t = \frac{l_i - \bar{l}}{\sigma} \quad \text{и} \quad \bar{l} = 0, \qquad \sigma = 1$$

the function is represented as a probability function according to the law of normal distribution. This function is called the standard normal distribution function, and its values are given in tabular form [7]. When expressing the normal distribution function $F(l_i)$ with parameters σ and l by the standard function with normal distribution $F^*(l_i)$, we obtain

$$F(l_i) = F^*\left(\frac{l_i-\bar{l}}{\sigma}\right).$$

Now we can determine the probability that the random value $l_i$is in the range from -∞ to l_0:

$$P(-\infty < l_i < l) = F^*\left(\frac{l-\bar{l}}{\sigma}\right) - F^*\left(\frac{-\infty-\bar{l}}{\sigma}\right) = F^*\left(\frac{l-\bar{l}}{\sigma}\right),$$

where $F^*\left(\frac{-\infty-\bar{l}}{\sigma}\right) = 0$

default

$$\delta = P(-\infty < l_i < l) = F^*\left(\frac{l-\bar{l}}{\sigma}\right) \tag{8}$$

If the standard normal distribution function is equal to δ, the li value corresponding to the argument $\left(\frac{l-\bar{l}}{\sigma}\right)$ is determined, then the value of the additional protective zone is determined from the expression $l_i = \left(\frac{l-\bar{l}}{\sigma}\right)$.

$$l = l_i\sigma - \bar{l}; \tag{9}$$

The size of the protective zone is determined by the formula (1) (usually in laboratory conditions l_0= 0.

Our hypothesis determines whether or not the experimental results obtained using the cultivator aggregate model are consistent or inconsistent. If it matches, the size of the protective zone lying within the limits of the permissible damage to plants is indicated. Therefore, the size of the protective zone for cultivators during cultivation of crops can be indicated.

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