TREATMENT QUALITY ASSESSMENT OF SUNFLOWER INTER-ROW WIDTHS WITH ASYMMETRIC JOINING OF CULTIVATOR TO TRACTOR

Volodymyr Bulgakov[1], Semjons Ivanovs[2], Valerii Adamchuk[3], Volodymyr Nadykto[4], Volodymyr Kyurchev[4], Vadym Yaremenko[1], Liudmyla Krasiuk[5]
[1]National University of Life and Environmental Sciences of Ukraine, Ukraine;
[2]Latvia University of Life Sciences and Technologies, Latvia;
[3]Institute of Mechanics and Automation of Agricultural Production of the National Academy of Agrarian Sciences of Ukraine, Ukraine;
[4]Dmytro Motornyi Tavria State Agrotechnological University, Ukraine;
[5]National Scientific Center "Institute of Agriculture" of the National Academy of Agrarian Sciences of Ukraine, Ukraine
semjons@apollo.lv

Abstract. Almost all existing units for mechanical processing of inter-row widths of row crops (corn, sunflower, soybeans, etc.) are symmetrical. In this case, the ratio of the tractor track to the row crop's inter-row widths is an even integer (*k*). This article presents the study results of a machine-tractor unit in which the value k equals 3; that is, it is odd. As a result, an asymmetric unit was obtained, in which the cultivator is displaced in the transverse direction relative to the tractor symmetry axis by half the inter-row width, equal to 70 cm. The width fluctuations of sunflower plant protective zone formed by such machine-tractor unit are rather low-frequency. At a speed of 1.9 $m \cdot s^{-1}$, the main variance spectrum of these oscillations is concentrated in the frequency range 0-0.9 m^{-1} or 0-0.27 Hz. With an increase in the unit movement speed to 2.4 $m \cdot s^{-1}$, this diapason narrows to 0-0.6 m^{-1} (0-0.23 Hz). At the same time, an increase in the movement speed of the studied unit from 1.9 to 2.4 $m \cdot s^{-1}$ did not lead to a significant change in the mean of the width and variance of the sunflower row protective zone oscillations. The actual difference between the means of this zone (0.6 cm) turned out to be less than LSD_{05}, equal to 0.8 cm. In addition to this, the null hypothesis about the equality of the compared of this parameter fluctuation variances was confirmed. Calculations have established that the possible deviation frequency of the sunflower plant protective zone width actual value of ± 1 cm from the established one can reach 0.007 m^{-1} or one release per 143 m of the path travelled by the unit at a speed of 1.9 $m \cdot s^{-1}$. When the machine-tractor unit moves in the sunflower inter-row widths at a speed of 2.4 $m \cdot s^{-1}$, the value of this indicator is 0.009 m^{-1} or one release per 111 m of the path. According to the results of experimental studies, real damage (cutting) of sunflower plants for both unit operation modes did not exceed 0.9%. The weed destruction in the inter-row widths of this crop was 98.5%.

Keywords: inter-row, cultivator, straightness of motion, inter-row width protective zone, soil tillage depth.

Introduction

The main physical object that performs fieldwork is an agricultural machine. According to our definition, it is an autonomous mobile energy-technological complex for performing one or several operations of agricultural production at the same time with specified agrotechnical requirements [1]. If the energy base of this complex is a tractor, then it (the complex) is called a machine-tractor unit (MTU).

In agricultural production, a special place among the units is occupied by those that cultivate crops sown with wide (45-90 cm) inter-row widths (corn, sunflower, soybeans, etc.). This is due to increased agrotechnical requirements for the straightness of such MTU movement. In Ukraine, for example, these requirements are as follows. The row straightness of row crops is considered satisfactory if the variance of their oscillations is not more than 12.50 cm^2 and the cutoff frequency of the normalized spectral density of these oscillations is not more than 0.25 m^{-1} [2]. Recall that the cutoff frequency of the normalized spectral density of a stationary oscillatory process (ω_c) determines the frequency limit 0- ω_c, in which at least 95% of the oscillation variance of the parameter under study is concentrated. Instead of ω_c, you can use the correlation interval, which is a segment of the path from the origin to the first intersection of the abscissa axis by the normalized correlation function of the estimated oscillatory process. For rows of row crops, the acceptable value of this indicator should be in the range of 0-25 m [3]. So far, all MTUs for row crops have been symmetrical [4-9]. For such units, with their position aligned in the longitudinal direction, the resistance centre of one or more machines used is in a plane that passes through the tractor symmetry longitudinal axis. This is ensured by each row seeder having an even number of row sections. The tractors used for this are equipped with a running system for which the following two conditions are met:

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$$B_r - 2\Delta \geq B_k \tag{1}$$

and

$$k = \frac{B_t}{R_r} \in \text{even integer}, \tag{2}$$

where B_r, Δ – inter-row and protective zone widths of row crop respectively, m;
B_k – tractor wheel width, m;
B_t – tractor track, m.

The problem associated with the condition (1) failure can be solved by equipping the tractor (if technically possible) with narrower tires. To reduce soil compaction, they can be doubled using special devices [10]. In practice, simultaneous non-fulfilment of conditions (1) and (2) is quite possible. In this case, the following way of solving the problem is acceptable. It consists of wider but necessarily doubled tires with reduced air pressure. This can lead to a decrease in soil compaction, which practically does not affect the seeding quality of the seeder sections that follow the tractor wheel tracks [2]. The essence of the variant under which condition (1) is met but condition (2) is not will be shown by the example of the HTZ-16131 tractor (Kharkiv, Ukraine), potentially aggregated with a 12-row row-crop seeder and cultivator, the operating width of which is 8.4 m. This tractor has a track B_t = 2100 mm and is equipped with tires of the size 16.9R38. Since the width of these tires is B_k = 430 mm, they, according to condition (1), fit into the row spacing B_r = 700 mm with a protective zone width $\Delta \leq$ 135 mm.

At the same time, condition (2) is not met for this tractor since $k = 2100 \cdot 700^{-1} = 3$. If a row cultivator is symmetrically joined to it (Fig. 1a), then the tractor wheels will be placed in the growth zones of plants, that is, in their rows.

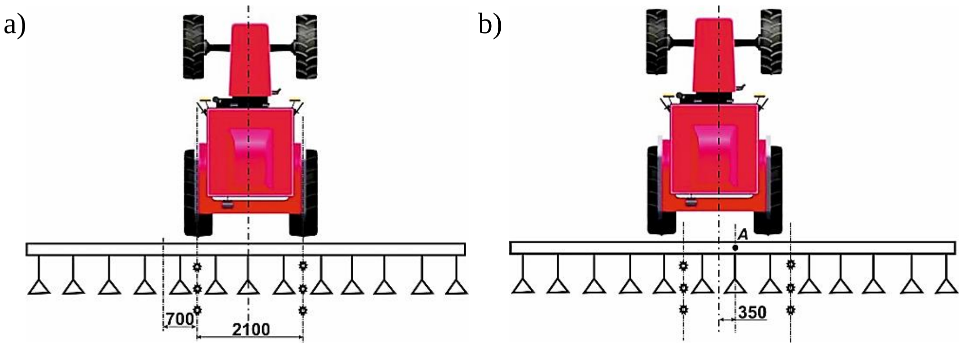

Fig. 1. **Symmetric (a) and asymmetric (b) diagram joining of the HTZ-16131 tractor with a 12-row row cultivator**

The way out of this situation is to carry out a transverse displacement of the cultivator centre (point A) relative to the tractor symmetry axis by equal to half the inter-row width. In this case, this implements to the right by $B_r \cdot 2^{-1}$ = 350 mm (Fig. 1b). After that, the tractor wheels are located in the inter-row widths of the row crop, but MTU becomes asymmetric with a constant eccentricity of 350 mm. This is the shoulder through which the longitudinal component of the cultivator traction resistance creates a turning momentum acting on the tractor in the horizontal plane. This turning momentum may affect the frequency and duration of the tractor driver's influence on the tractor controls. Constant adjustment of its movement direction causes transverse deviations of the row cultivator working bodies. Mechanical damage to cultivated plants is dangerous at certain values of these deviations. It should be noted that the work quality of row cultivators has been and remains the object of researchers' close attention [11-13]. The range of problems considered by them concerns the study of the dependence of damage to cultivated plants on the influence of the MTU speed movement in inter-row widths, the size of their protective zone, the soil tillage depth, etc. However, such studies are carried out only with symmetrical row MTUs. And they have a more or less significant disturbing turning momentum from the side of a row cultivator that can occur if there is a difference in the resistance of its left and right wings. But, as the practice of studies [14] has shown, the value of this difference in resistance, even for row MTUs with an operating width of up to 11 m, is negligible.

We have not found any studies of the asymmetric row units' work quality to date. Based on this, the aim of this article is an experimental effect assessment of the cultivator asymmetric joining to a tractor on the quality of its work in inter-row widths of row crops.

Materials and methods

The unit (Fig. 2) consisting of a tractor HTZ-16131 (Ukraine) and a twelve-row cultivator KRNV-8.4 (Elvorti, Ukraine) was taken as a physical object of the experimental studies. A brief technical description of this machine-tractor unit is presented in Table 1.

Fig. 2. HTZ-16131 tractor with KRNV-8.4 cultivator

Table 1

Technical characteristics of weeding machine-tractor unit

Property	Value
Tractor weight, kg	8160
Weeder weight, kg	1900
Weeder number sections	13
Distance between weeder sections, cm	70
Weeder operating width, m	8.4
Tractor wheelbase, mm	2860
Tractor track B_t, mm	2100
Tractor tires	16.9R38

The joining of the cultivator to a tractor with a right-sided (rear view) transverse displacement of 350 mm was carried out by moving its hinged mechanism to the left at the same distance. The cultivator sections were set to a tillage depth of 6 cm. The field with sunflowers was divided into plots, each 250 m long, for experimental studies. The first 50 m of each plot were used to start MTU. This was followed by its operating movement along a plot 200 m long. The speed of this movement (V_o) was calculated from the equation $V_o = 200\ t^{-1}$, where t is the time for the unit to pass through a plot 200 m long. The time was recorded using a KHP PC3860 electronic stopwatch (China) with a measurement error of 0.01 s. Before carrying out the experimental studies, the following were measured: i) moisture and density of the soil in a layer of 0-10 cm; ii) height of sunflower plants; iii) density of weeds in sunflower rows; iv) straightness of sunflower rows.

The instruments and methodology used in determining soil moisture and density are described in the work [15]. The height of sunflower plants was determined along the field diagonal with a ruler with a measurement error of ± 0.5 cm. The number of such measurements was 300, and the measurement step was 1 m.

Weed density ($g \cdot m^{-2}$) was determined in 30 inter-row widths of the field using a wooden frame with an area of 1 m^{-2}. The distance between the zones of measurements performed along the diagonal of the field was at least 10 m. The mass of weeds that fell into the frame zone was determined using an Axis AD 200 electronic scale (Poland), the measurement error of which was 0.001 g. After the MTU operating movement, the following was measured in duplicate: i) the depth of soil loosening in the inter-row widths of sunflower; ii) the width of the protective zone; iii) the number of damaged sunflower plants. The depth of tillage with weeder was measured by the traces of the passage of two outside and one middle cultivation sections in two repetitions. The measurement step of this parameter was 0.2 m, and the number of measurements in each repetition was at least 300. To measure the soil tillage depth, we used a kit designed by us based on the ultrasonic sensor HC-SR04 (China) and the Arduino UNO board (Italy). The error in measuring the tillage depth with this kit does not exceed 0.5 cm. The width of the sunflower protective zone was determined with a ruler with a measurement error of 0.5 cm. The number of measurements in each row, performed with a step of 1 m, was at least 200. The experimental data obtained in this case were used to calculate the mean, variance, normalized correlation functions, and spectral densities of fluctuations in the width of the protective zone. In addition, the deviation frequency of this zone width (*N*) from the established value was estimated. For this, we used the equation [16]:

$$N = \frac{1}{2 \cdot T_{pp}} \cdot \exp\left(-\frac{\Delta^2}{2 \cdot \sigma^2}\right), \tag{3}$$

where Δ – tolerance for fluctuations in the width of the sunflower row protective zone width, ± cm;
σ – standard deviation of the sunflower row protective zone width, ± cm;
T_{pp} – mean of oscillation half-period of the normalized correlation function of the protective zone width changing process, m.

To determine the number of damaged sunflower plants, a frame with an area of 0.25 m^2 was used with the following dimensions: width – 0.25 m; length – 1 m. This frame was placed on sunflowers rows in 50 places on the field diagonal. The distance between measurements was at least 10 m. The index of plant damage (N_s, %) was determined from the ratio of damaged sunflower plants (N_d) to their total number (N_t) in the frame zone:

$$N_s = \frac{N_d}{N_t} \cdot 100\% \cdot \tag{4}$$

Similarly, we determined the degree of weed destruction in the sunflower inter-row widths after the passage of MTU.

Results and discussion

The place of the field experiments was: Ukraine, Melitopol (46º50′56″ north latitude, 35º21′55″ east longitude, altitude: 37 m). The research conditions are presented in Table 2. MTU worked in the sunflower inter-row widths, the straightness of which met the agrotechnical requirements adopted in Ukraine. Firstly, the variance of sunflower row oscillations was 7.65 cm^2, which is less than the normative value of this parameter, equal to 12.5 cm^2.

Table 2

Conditions for inter-row cultivation of sunflower

Index	Value
One-side protective zone	8.0
Soil cultivation depth, cm	6.2 ± 0.2
Mean height of sunflower plants, cm	18.3 ± 0.5
Soil humidity, %	16.5
Soil bulk density, g·cm^{-3}	1.22
Weeds density, g·m^{-2}	115.8

Secondly, the normalized correlation function correlation interval of the sunflower row trajectory oscillations was 20 m (Fig. 3). This is included in the normative range of this estimated indicator, equal to 0-25 m [3].

A low-frequency spectrum characterized fluctuations in the width of the sunflower row protective zone. In the inter-row widths, MTU worked at two speeds. Their means were 1.9 and 2.4 m·s^{-1}. When the unit moved at a speed of 1.9 m·s^{-1}, the correlation interval length of the normalized correlation function of this parameter oscillations was 10 m (curve 1, Fig. 4). With a higher speed of row-crop MTU (2.4 m·s^{-1}), this interval expanded to 13.2 m (curve 2, Fig. 4). The values of oscillation half-periods (T_{pp}) of the considered normalized correlation functions are approximately 25 m (curve 1) and 23 m (curve 2).

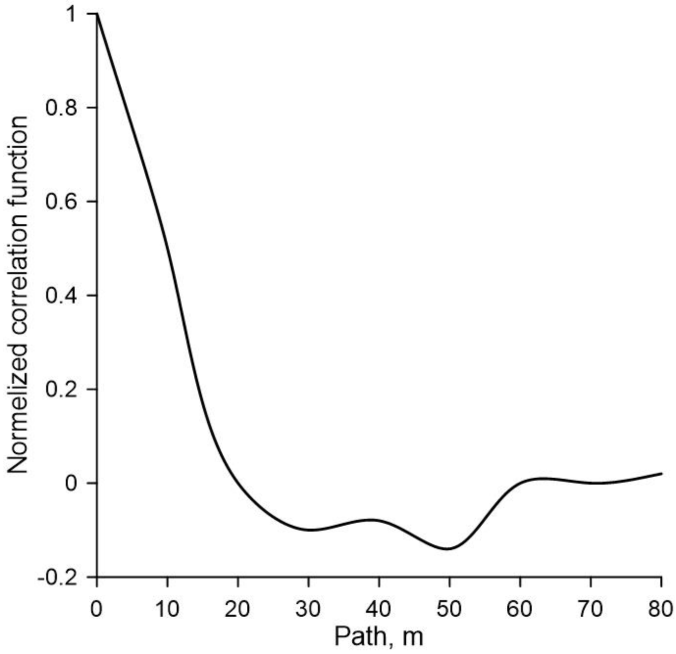

Fig. 3. **Normalized correlation function oscillations of sunflower rows**

The normalized spectral fluctuation densities of the studied process (Fig. 5) confirm that with an increase in the MTU movement speed from 1.9 to 2.4 m·s^{-1} (i.e., by 26%), the spectrum of fluctuations in the width of the sunflower row protective zone has become narrower. From their analysis, it follows that at the MTU speed of 1.9 m·s^{-1}, the dispersion main spectrum in the width fluctuations of the sunflower plant protective zone is concentrated in the frequency range of 0-0.9 m^{-1} or 0-0.27 Hz (curve 1, Fig. 5). With an increase in the MTU speed to 2.4 m·s^{-1}, it narrows to 0-0.6 m^{-1} (0-0.23 Hz). In principle, this result can be explained by an increase in the inertial properties of the row-crop MTU with an increase in its speed from 1.9 to 2.4 m·s^{-1}.

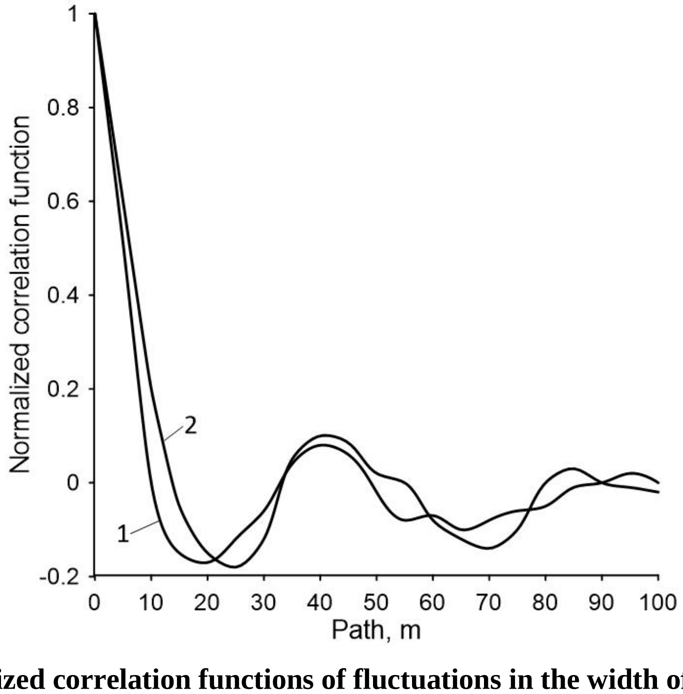

Fig. 4. **Normalized correlation functions of fluctuations in the width of the sunflower row protective zone when MTU moves at different speeds:** 1 – 1.9 m·s^{-1}; 2 – 2.4 m·s^{-1}

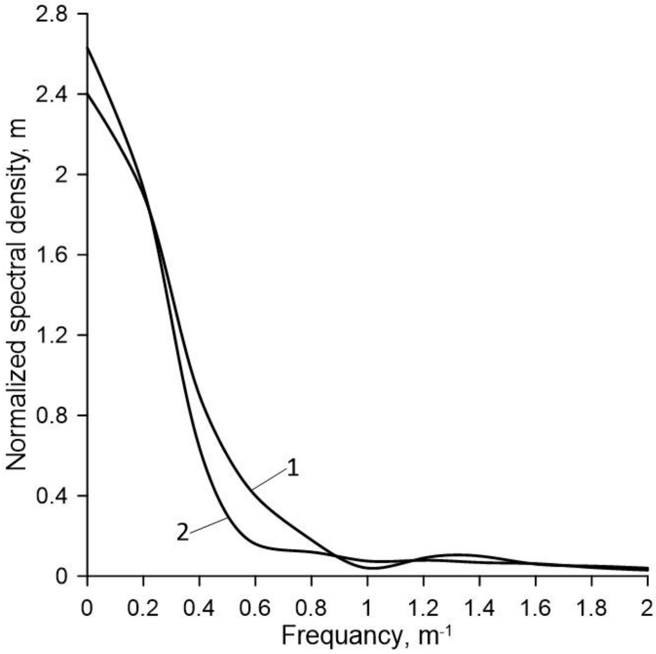

Fig. 5. **Normalized spectral densities of fluctuations in the width of the sunflower row protective zone when MTU moves at different speeds:** 1 – 1.9 m·s^{-1}; 2 – 2.4 m·s^{-1}

At the same time, there were no significant differences between other statistical parameters of the sunflower plant protective zone width when changing the speed mode of the unit. Regarding its movement at a speed of 1.9 m·s^{-1}, the mean of the protective zone width varied within 15.8 ± 0.6 cm. When MTU operated at a speed of 2.4 m·s^{-1}, this parameter changed within 15.2 ± 0.5 cm. The resulting difference between the compared means of the protective zone widths of 0.6 cm is insignificant since it is less than the LSD05 of 0.8 cm (Table 3).

Table 3

Statistical characteristics of sunflower protection zone width

Index	**Value**	
MTU operating speed, m·s^{-1}	1.9	2.4
Mean protective zone, cm	15.8 ± 0.6	15.2 ± 0.5
Mean error, cm	0.30	0.25
Mean LSD_{05}, cm	0.8	
Standard deviation σ, ± cm	0.71	0.77
Variance, cm^2	0.50	0.60
Coefficient of variation, %	4.5	5.0

Moreover, at least at a statistical level of 0.05, the null hypothesis about the equality of the compared dispersions of the sunflower plant protective zone width fluctuations is also not rejected. This is confirmed by the smaller F-test real value, which was 1.20, compared to the table value, equal to 1.39. In favour of the low variability of changes in the protective zone width under consideration is indicated by the corresponding values of the variation coefficients. As follows from the analysis of Table 3, their level does not exceed 5%. The agrotechnical requirements in Ukraine establish that the width permissible deviation of the row plant protective zone (Δ) should not exceed ± 1 cm. As a result of calculations using formula (3), it was found that the possible frequency of this requirement violation by the unit operating at a speed of 1.9 m·s^{-1} is 0.007 m^{-1} or one release per 143 m of the path. When MTU moves in sunflower inter-row widths at a speed of 2.4 m·s^{-1}, the value of this indicator is 0.009 m^{-1} or one release per 111 m of the path. Such high rates of maintaining the tolerance for the deviation of the protective zone width from the given one had a corresponding effect on the quality of the cultivator work in the sunflower inter-row widths. According to the results of the field studies, real damage (cutting) of cultivated plants for both modes of MTU operation did not exceed 0.9%. The destruction of weeds in the sunflower inter-row widths was 98.5%.

Conclusions

1. The primary condition for the possibility of using a tractor for the mechanical treatment of row crops is the fit of its wheel width into the inter-row widths of these crops. An additional condition is that the ratio of the tractor track to row crop inter-row widths must be even. In the case of an odd value of this ratio, the unit can be composed of the transverse displacement of the row cultivator relative to the tractor symmetry longitudinal axis. This displacement is equal to half the inter-row widths of the row crop.
2. In the field, an asymmetric unit was studied as part of a tractor with a wheel track of 2100 mm and a 12-row cultivator for processing sunflowers with inter-row widths of 70 cm. It has been established that protective zone oscillations of the tilled crop plants are low-frequency in this case. At the MTU speed of 1.9 $m \cdot s^{-1}$, the primary variance spectrum of these oscillations is concentrated in the frequency range 0-0.9 m^{-1} or 0-0.27 Hz. With an increase in the speed of MTU 2.4 $m \cdot s^{-1}$, this range narrows to 0-0.6 m^{-1} (0-0.23 Hz).
3. An increase in the movement speed of the studied unit from 1.9 to 2.4 $m \cdot s^{-1}$ did not significantly change the width mean and variance of the sunflower row protective zone oscillations. The valid difference between the mean values of this zone (0.6 cm) turned out to be less than LSD_{05}, equal to 0.8 cm. In addition to this, the null hypothesis about the equality of the compared variances of these parameter oscillations was confirmed.
4. Calculations have established that the possible frequency of the width actual value deviation of the sunflower plant protective zone by ± 1 cm from the established one can reach 0.007 m^{-1} or one release per 143 m of the path moved by the unit at a speed of 1.9 $m \cdot s^{-1}$. When moving MTU in sunflower inter-row widths at a speed of 2.4 $m \cdot s^{-1}$, the value of this indicator is 0.009 m^{-1} or one release per 111 m of the path. The damage (cutting) of sunflower plants for both modes of operation MTU did not exceed 0.9%, and the destruction of weeds in the inter-row widths of this crop was 98.5%.

References

[1] Bulgakov V., Adamchuk V., Nadykto V., Ruzhylo M. Aggregation of agricultural equipment is one of the current problems of agricultural mechanics. Bulletin of Agricultural Science, 2022, vol. 11, pp. 48-55, DOI: 10.31073/agrovisnyk202211-07. (in Ukrainian)

[2] Nadykto V., Karaiev O., Kyurchev V., Beloev H. 2019. The efficiency of tractor application with articulated frame for cultivating arable crops, in: Modern Development Paths of Agricultural Production: Trends and Innovations, 2019, Springer, Cham., pp. 161-167. DOI: 10.1007/978-3-030-14918-5_17.

[3] Adamchuk V., Bulgakov V., Nadykto V., Kyurchev V., Ihnatiev Y., Boris M. The study of misalignment of rows of row cultures using a new indicator. Bulletin of Agricultural Science, 2021, vol. 8, pp. 39-46, DOI: 10.31073/agrovisnyk202108-05.

[4] Qi J.T., Jia H.L., Li Y., Yu H.B., Liu X.H., Lan Y. Bin, Feng X.Z., Yang Y.X. Design and test of fault monitoring system for corn precision planter. International Journal of Agricultural Biological Engineering, 2015, vol. 8, pp. 13-19, DOI: 10.3965/j.ijabe.20150806.1968.

[5] Wang W., Wu K., Zhang Y., Wang M., Zhang C., Chen L. The Development of an Electric-Driven Control System for a High-Speed Precision Planter Based on the Double Closed-Loop Fuzzy PID Algorithm. Agronomy, 2022, vol.12, p. 945, DOI: 10.3390/agronomy12040945.

[6] Lodgo D., Scarabel L., Sattin M., Pederzoli A., Morsiani C., Canestrale R., Tommasini M.G. Combination of Herbicide Band Application and Inter-Row Cultivation Provides Sustainable Weed Control in Maize. Agronomy, 2020, vol. 10, №20, doi:10.3390/agronomy10010020.

[7] Perez-Ruiz M., Carballido J., Agüera J., Rodríguez-Lizana A. Development and Evaluation of Combined Cultivator and Band Sprayer with a Row-Centering RTK-GPS Guidance System. Sensors, 2013, vol. 13, pp. 3313-3330, doi:10.3390/s130303313.

[8] Martelloni L., Frasconi C., Fontanelli M., Raffaelli M., Peruzzi A. Mechanical weed control on small-size dry bean and its response to cross-flaming. Spanish Journal of Agricultural Research, 2016, vol. 14, is. 1, e0203, DOI: 10.5424/sjar/2016141-7976.

[9] Yu Wang, Xiaobo Xi, Meng Chen, Yangjie Shi, Yifu Zhang, Ruihong Zhang, Baofeng Zhang, Jiwei Qu. Design of Experiment on Reciprocating Inter-Row Weeding Machine for Strip- Seeded Rice. Agriculture, 2022, vol. 12, №1956, DOI: 10.3390/agriculture12111956.

[10] Fomin A.A. Tractors VERSATILE with a Classic Frame: APPLICABILITY. International Agricultural Journal, 2018, Vol. 2, pp. 81-83, DOI: 10.24411/2587-6740-2018-12033. (In Russian).

[11] Presnyakov V.A., Kaminskiy N.S. Indicators of quality of functioning of the MTA row, interrow processing of soybean crops. Journal of Physics: Conference Series, IOP Publishing, 2019, vol. 1177, № 012003, doi:10.1088/1742-6596/1177/1/012003.

[12] Wu C. Y. et al. Design and experiment of 2BYS-6 type paddy weeding-cultivating machine. Transactions of the Chinese Society for Agricultural Machinery, 2009, vol. 40, is. 7, pp. 51-54.

[13] Ryndyaev V.I. Improving the design of the cultivator working body for inter-row cultivation of weeding crops. Engineering of nature management, 2021, vol. (4(22), pp. 59-62, DOI: 10.37700/ enm.2021.4 (22). pp.59-62. (In Ukrainian).

[14] Kutkov G.M. et al. Wide-width weeding unit with an automatic control system. Mechanization and electrification of agriculture, 1984, vol. 2, pp. 38-41. (In Russian).

[15] Bulgakov V., Nadykto V., Ivanovs S., Dukulis I. Improving the performance of a ploughing tractor by means of an auxiliary carriage with motorized axle. Journal of Agricultural Engineering, 2021, vol. 52, pp. 9-16, DOI: 10.4081/jae.2021.1109.

[16] Bulgakov V., Nadykto, V., Kaminskiy V., Ruzhylo Z., Volskyi V., Olt J. Experimental research into the effect operating speed on uniformity of cultivation depth during tillage in fallow field. Agronomy Research, 2020, vol. 18(3), pp. 1962-1972, DOI: 10.15159/AR.20.200.