FIELD EXPERIMETAL RESEACH OF THE COMBINED FERTILIZING-SEEDING MACHINE-TRACTOR AGGREGATE

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Abstract: *The scientific problem of this study is the justification of the expediency of combining the technological operations of sowing cereals and applying the main and starting doses of mineral fertilizers when using a combined machine and tractor unit (aggregate). During the research there were used methods of conducting field experiments using standard equipment. During the planned experiments there were used correlation methods and methods of numerical calculations on a PC. The comparative studies of the quality of barley sowing with basic and modernized fertilizer-sowing units showed the following values of qualitative indicators. So, the coefficient of seed depth variation of the base unit was – 8.2%, and the combined (modernized) unit – 4.7%; The uniformity of seed distribution along the length of the line for the basic unit is – 63.8%, for the modernized unit – 84.9%; Field germination of seeds when sowing the basic unit is 80.4%, modernized – 87.4%. Thus, when using the combined fertilizer-seeding unit, the uniformity of seed distribution along the length of the string will be substantially increased. At the same time, the field germination of seeds will increase, and the coefficient of variation in the depth of seed placement in the furrow will decrease. Based on the results of field experimental studies, an increase in the yield of spring wheat and barley was found in the application of a combined fertilizer-seed aggregate with the simultaneous introduction of a basic fertilizer-seeded fertilizer into the soil and sowing of cereals with the application of a starting dose of mineral fertilizer in comparison with the known schemes of such operations. The obtained results confirm the expediency of combining these technological operations with one pass of the combined machine-tractor unit (aggregate).*

KEYWORDS: *COMBINED AGGREGATE, SEEDER, MINERAL FERTILIZERS, FIELD EXPERIMENTS, QUALITY INDICATORS, FIELD GERMINATION, YIELD*

1. Introduction

One of the ways to improve the effectiveness of agricultural machinery in the production of crop production is the use of combined units, in which several operations are performed in a single pass. This makes it possible to reduce labor costs and fuel consumption per unit of grown production, and also reduce the effect on the soil of wheeled (running) systems of mobile machines [1-6].

To increase the efficiency of seeding of the planting crops, the leading firms producing seeding equipment produce high-performance combined seeding units. But simultaneously with the increase of the indicators of technological efficiency when using combined sowing units, a need arises for the use of more powerful power units (tractors), and they are characterized by a high cost.

Therefore, the search for ways to comprehensively improve the effectiveness of seeding technology there is an urgent task in the field of mechanization of agricultural production.

On the basis of previous research and design work, a new design and technological scheme for a combined aggregate for intrasoil fertilizer and simultaneous sowing of grain crops using a wheeled tractor, traction class 1.4 (Figure 1) was proposed. The main advantage of this fertilizer-sowing machine-tractor unit is the possibility of placing the main dose of mineral fertilizers in the soil below the simultaneously sown seeds in the form of a ribbon, i.e. in the zone where the roots of grain crops are located, which in turn increases the efficiency of using the basic dose of mineral fertilizers.

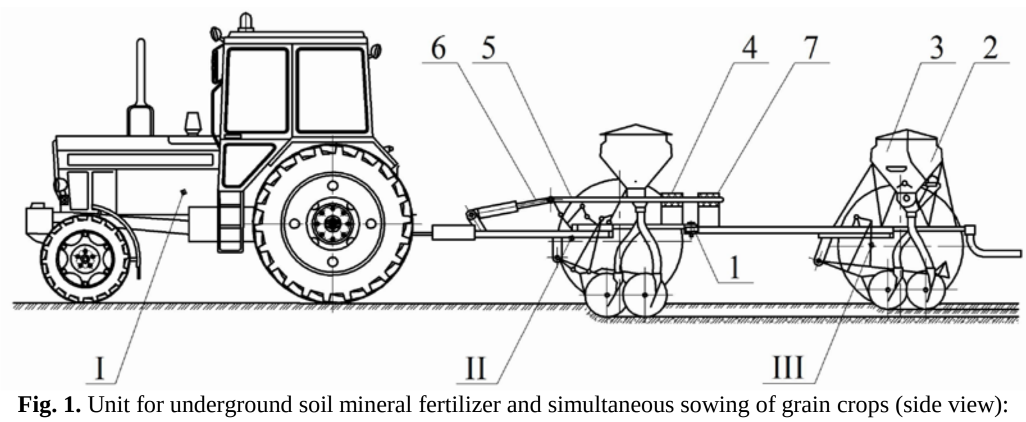


Fig. 1. Unit for underground soil mineral fertilizer and simultaneous sowing of grain crops (side view): I – tractor; II – machine for applying the main dose of mineral fertilizers; III – machine for sowing grain and introducing a starting dose of the mineral fertilizers: 1 – the hinge; 2 – bunker for starting fertilizers; 3 – seed hopper; 4 – a directing element; 5 – blocking element; 6 – the rod; 7 – fixing element

2. Preconditions and means for resolving the problem

2.1. Analysis of recent research and publications

When creating the sowing units, the two main directions can be found: the creation of aggregates based on one operating machine, and the creation of specialized combined units. The practice of using aggregates that are made up of individual machines allows, if necessary, to carry out different technological operations, and the use of combined sowing units that perform several technological operations in one pass makes it possible to reduce the number of passes of the unit and compaction of the soil, increase the yield of agricultural crops, and keep the soil moisture content [1-6].

On the basis of the analysis of the agrotechnological peculiarities of sowing of agricultural crops, it was suggested, when sowing grain crops, to combine the implementation of the crop with the introduction of the starting and the main dose of mineral fertilizers with the application of a two-machine combined seeding unit using a two grain seeders and a tractor of traction class 1.4.

2.2. Purpose of the study

The purpose of the study is the experimental substantiation of the expediency of combining technological operations of sowing grain crops and application the starting and main dose of mineral fertilizers when using a combined seeding unit.

2.3. Methods of research

For the experimental study of the expediency of combining the process of sowing grain crops and introducing a starting and basic dose of mineral fertilizers, field experience was also established in the production conditions in the research fields of the Yelenovskoye Research Farm of the Fastovsky District of the Kiev Region during the sowing of spring wheat and barley according to known methods [7-9].

The field research conditions were determined according to the existing methods and make up: previous cultivation pre-sowing cultivation, soil type chernozem, relief of the field level, microrelief - leveled, soil moisture content: in the layer 0 – 5 cm it was 17.4 – 18.7%, in the 5 – 10 cm layer it was 20.1 – 22.3%, the soil hardness: in the 0 – 5 cm layer it was 0.20 – 0.35 MPa, in the layer 5–10 cm it was 1.38 – 1.57 MPa, weed infestation it was 13 $g \cdot m^{-2}$.

The investigations were carried out on an experimental equipment – on a combined seeding unit, which was formed from two grain drills (Figure 2).

Fig. 2. General view on the field experimental machine – tractor aggregate

The first seeder of the sowing unit provides for the in-soil application of the required starting dose of mineral fertilizers to the required depth with a row spacing of 25 cm, and the second seeder – provides sowing of grain crops to the appropriate depth with a row spacing of 12.5 cm with simultaneous application of the main dose of mineral fertilizers. To assemble seeders among themselves and with the tractor, a special coupling was designed and manufactured, the use of which will ensure the necessary maneuverability of the combined unit (aggregate) during operation and transportation [10].

To conduct field experimental studies, we have developed a general methodology for experimental studies.

Experimental field research, which is defined in the program, involves the use of both standard and partial techniques:

– methodology for determining the conditions for conducting the research;

– methodology for determining the main agrotechnical indicators;

– the methodology of conducting laboratory and field studies to determine the influence of parameters and operating conditions of the unit (aggregate) on the quality of sowing;

– the methodology for conducting field studies to justify the feasibility of combining technological operations in a single pass of a combined seeding unit.

The general methodology of the field experimental research included the selection of the necessary instruments, equipment, devices and techniques that will be used for fixing and measuring of different parameters.

For the experimental seeding on given field, the areas were identified that were sown for one day according to the following schemes: 1) pre-sowing the soil tillage without the application of granular mineral fertilizers (control); 2) with a continuous surface application of the starting dose of fertilizers, pre-sowing soil tillage and sowing of seeds with the simultaneous introduction of a basic dose of fertilizers into the soil; 3) standard pre-sowing soil tillage and seed sowing with the simultaneous introduction of fertilizer into the soil with a starting dose [11].

The sowing process was carried out by a combined aggregate to a seeding depth of 5 cm, a fertilizer depth of 8 cm with a seeding machine speed of 10 $km \cdot h^{-1}$ (2.78 $m \cdot s^{-1}$), which were justified by the results of previous laboratory-field experimental studies. The evaluation of the efficiency of sowing was carried out according to the yield ($q \cdot ha^{-1}$), which was determined by the standard method during the full maturity of the crops by manually collecting them from the area, which is limited to a 1 m x 1 m frame and further weighing.

Fig. 3. Experimental aggregate during providing the research

In addition, experimental studies were carried out comparing seed productivity with basic and modernized seeding units. The seeding depth variation coefficient (%), the uniformity of seed distribution in a row (%) and seed germination (%) were used as an indicators of crop efficiency. For this purpose, sowners were raised during the sowing and, by measuring at five points of the field, the depth of sowing of seeds and the number of seeds on one running meter of the row were monitored five times in succession, and after the shoots were opened a row at five points of the field and the number of sprouted and not germinated seeds were determined.

3. Results and discussion

Experimental studies were carried out using the standard matrix 2 ** 3 [9, 12, 13]. Number of experiments: 9. The repetition of the experiments was determined according to the established procedure [9] to ensure the required accuracy of the studies and is at least 3.

For each series of experiments, the arithmetic mean of the measured value was determined as a product of these values effected by their frequencies

$$\bar{X} = \frac{1}{n}\sum_{i=1}^{n} x_i \cdot f(x_i). \quad (1)$$

Estimation of the dispersion of the actual values of the measured values with respect to their mean value is characterized by the root-mean-square deviation and dispersion [12, 13].

Dispersion of a discrete random variable is defined as the sum of products of squares of deviations of the actual value from the mathematical expectation by the corresponding probability:

$$D_x = \sum_{i=1}^{n}\left(x_i - M_x\right)^2 \cdot p(x_i). \quad (2)$$

Then for a continuous random variable the expression (2) will have the form:

$$D_x = \int_{-\infty}^{+\infty} (x - M_x)^2 \cdot \varphi(x)dx. \quad (3)$$

Then for empirical determination of random variables:

$$\sigma^2{}_x = S_x^2 = \frac{1}{n}\sum_{i=1}^{n}\left(x_i - \bar{X}\right)^2 \cdot f_i, \quad \text{for } n > 30, \quad (4)$$

$$\sigma^2{}_x = S_x^2 = \frac{1}{n-1}\sum_{i=1}^{n}\left(x_i - \bar{X}\right)^2 \cdot f_i, \quad \text{for } n < 30. \quad (5)$$

The variance according to (2) – (5) has the dimension of the square of the dimension of the random variable.

The root-mean-square deviation is defined as the square root of the variance (4) and (5), which is taken with a positive sign:

$$\sigma_x = +\sqrt{D_x}. \quad (6)$$

The variability of the measured values is characterized by the coefficient of variation, which is determined by the ratio of the root-mean-square deviation (6) to the mathematical expectation (arithmetic mean) according to (1) of the corresponding random variable:

$$V = \frac{\sigma_x}{M_x}\left(\times 100\%\right). \quad (7)$$

Having obtained the data obtained as a result of experimental studies, it is necessary to verify their reproducibility and adequacy of the regression models obtained [12, 13].

To evaluate the reproducibility, the Cochran test was used

$$G = \frac{S_{u\max}^2}{\sum_{u=1}^{n} S_u^2} \le G_{tab.}(0{,}05;\, n;\, f_u), \quad (8)$$

where $G_{tab.}(0{,}05; n; f_u)$ – table value of the Cochran test at 5% significance level, with the number of experiments n and the number of degrees of freedom; $f_u = m-1$ – with the number of replicates m; $S_u^2, S_{u\max}^2$ – variance at the u-th level and its maximum value.

Dispersion (3.7) can be determined by the following way:

$$S_u^2 = \frac{1}{m-1}\sum_{i=1}^{m}\left(y_{uik} - \bar{y}_u\right)^2, \quad (9)$$

where y_{uik} – the value of the original parameter on the corresponding replication.

Then, in general, the error of the experiment is calculated using the following expression:

$$S_y^2 = \frac{1}{n}\sum_{u=1}^{n} S_u^2. \quad (10)$$

After determining the statistical indicators for each series of experiments, the results were processed to obtain a regression model in the form of a polynomial of the 2 and degree, which characterizes the influence of the factors and their interaction on the quality characteristics of the combined seeding unit. The general regression equation has the following form:

$$Y = b_0 + b_p X_p + \ldots + b_{pr} X_p X_r + \ldots. \quad (11)$$

The coefficients in equation (11) are determined according to the following expressions:

$$b_0 = \frac{1}{n}\sum_{i=1}^{n}\bar{y}_u,$$
$$b_p = \frac{1}{n}\sum_{i=1}^{n} X_p \bar{y}, \quad (12)$$
$$b_{pr} = \frac{1}{n}\sum_{i=1}^{n} X_p X_r \bar{y}.$$

This regression equation (11) is an empirical model of the process and describes the influence of individual factors and their interactions on the qualitative performance indicators.

The adequacy of the regression equation (11) is checked by the Fisher criterion:

$$F = \frac{S_{ad}^2}{S_y^2} < F_{tab.}(0{,}05;\, f_{ad};\, f_y), \quad (13)$$

where $S_{ad}^2 = \frac{1}{f_{ad}}\sum_{u=1}^{n}(y - \bar{y}_u)^2$ – variance (dispersion) of adequacy; $f_{ad} = n - k - 1$ – number of degrees of freedom of the variance of adequacy for the number of factors equal to k; $f_y = n(m-1)$ – number of degrees of freedom of variance of reproducibility.

Having checked the adequacy, it is necessary to evaluate the importance of regression coefficients (12), using the Student's test.

The regression coefficient is significant if:

$$\left|b_i\right| \ge t_{tab.}(0{,}05;\, f_y)\frac{S_y}{\sqrt{n}}, \quad (14)$$

where $t_{tab.}(0{,}05; f_y)$ – table value of the Student's test at 5% level of significance.

Since the effect of individual factors and their interactions, taking into account random perturbations and unaccounted for factors, has not been fully investigated, we will retain all the terms in equation (11) when processing the research data.

In addition, in order to determine the relationship between the values (between the initial parameter and the factor, and also the factors among themselves), a correlation analysis was carried out by determining the correlation coefficient between the parameters x and y:

$$r_{xy} = \frac{K_{xy}}{S_x S_y}, \quad (15)$$

where S_x, S_y – standard deviation of the corresponding parameters; K_{xy} – correlation moment.

If the correlation coefficient according to (15) is equal to zero, then the parameters are uncorrelated, provided that the correlation coefficient is greater than 0.7 the correlation is strong, 0.3-0.7 – average correlation, less than 0.3 – correlation is weak.

In this case, the root-mean-square error of the correlation coefficient is determined in this way:

$$S_r = \sqrt{\frac{1 - r_{xy}^2}{n-2}}. \quad (16)$$

The relationship between the values is significant in case that the value of the Student's test criterion is greater than its table value, i.e.:

$$t_r = \frac{r_{xy}}{S_r} \ge t_{tab.}. \quad (17)$$

With simultaneous action of several values on the optimization parameter, it is advisable to apply a multiple correlation coefficient. The tightness of the relationship between parameter x with parameters y, z can be determined from the following expression:

$$R_{x \cdot yz} = \sqrt{\frac{r_{xy}^2 + r_{xz}^2 - 2 r_{xy} r_{xz} r_{yz}}{1 - r_{yz}^2}}, \quad (18)$$

and the parameter of the positive with the boundaries of the possible change from 0 to 1. The zero value of the multiple correlation coefficient means that there is no linear relationship between the parameters, but the possible nonlinear one. If this coefficient is equal to 1, then there is a linear relationship, and all the experimental data lie in one plane, which can be considered as a response surface.

The square of the correlation coefficient is a determination that shows the proportion of changes in the flow and expresses the dependence of one parameter on the other parameter.

When processing the results of experimental studies, the application packages EXCEL, STATISTICA v 10.0 and MathCAD were used.

During the first stage of laboratory-field experimental studies, the influence of parameters and operating conditions of the combined fertilizer-seed aggregate on the indices of the quality of barley sowing was carried out with the simultaneous introduction of the starting and the main dose of mineral fertilizers into the soil.

In this case, the main factors are the depth of sowing of seeds and placing of the fertilizers, as well as the forward speed of the machine-tractor unit (aggregate). The depth of sowing of seeds was taken as 2 cm, 4 cm and 6 cm, the depth of placing of fertilizers into the soil was 7 cm, 8 cm and 9 cm, and the forward speed of the machine-tractor unit was 1.0 m·s^{-1}, 1.5 m·s^{-1} and 2.0 m·s^{-1} (i.e. 3.6 km·h^{-1}, 5.4 km·h^{-1} and 7.2 km·h^{-1}, respectively).

As a qualitative indicators of the work was adopted the coefficients of variation (in %) the location of seeds and mineral fertilizers along the row (furrows), the deviation of seeds and fertilizers relative to the row axis and the depth of laying of seeds and fertilizers in the furrow. In order to control the placement of mineral fertilizers, soybean seeds were sown in the furrow.

Field studies with barley sowing were carried out on sites with previous ploughing and pre-plant cultivation.

Based on the results of statistical processing of the results of field experimental studies, the following performance indicators of the combined fertilizer-seeding unit were obtained:

– uniformity of the distribution of mineral fertilizers (soybean seeds) along the row:

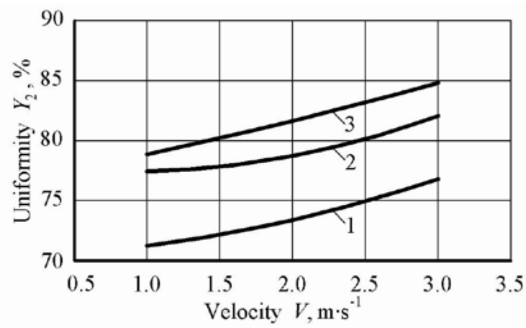


Fig. 3. The effect of the speed of the fertilizer-seeding unit on the uniformity of the distribution of fertilizers (soybean seeds) along the line at a different depths of laying fertilizers in the soil: 1 – H = 7 cm; 2 – H = 8 cm; 3 – H = 9 cm

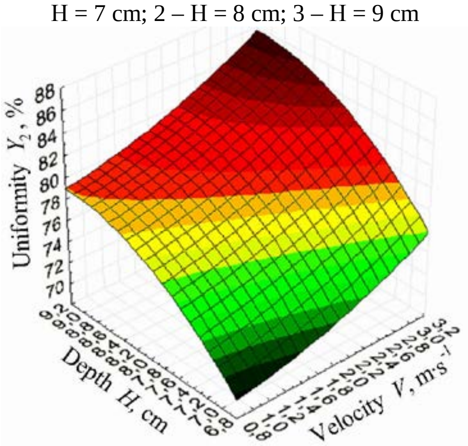


Figure 4. The effect of a forward speed of movement of the fertilizer-seed aggregate and the depth of fertilization in the soil on the response surface of the dependence of the uniformity of the distribution of fertilizers (soybean seeds) along the row

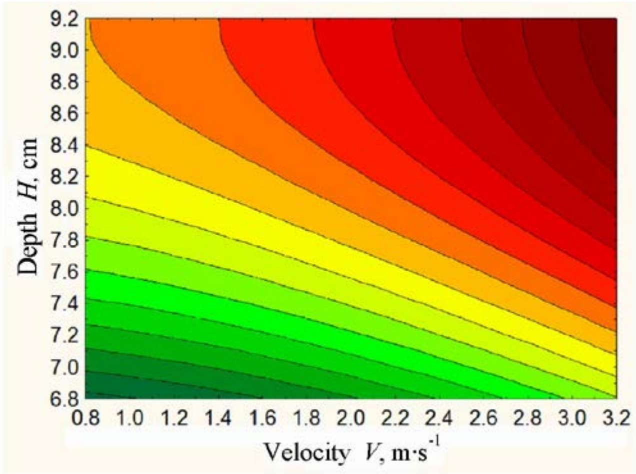


Fig. 5. Two-dimensional section of the dependence of the uniformity of the distribution of fertilizers (soybean seeds) along the row on the speed of movement of the fertilizer-seeding unit and the depth of fertilization in the soil

As a result of the studies (Figures 3, 4, 5) it was established that with an increase in the forward speed of movement of the fertilizer-seeding unit and the depth of placing of mineral fertilizers into the soil, the uniformity of their distribution at the bottom of the furrow will increase.

The regression equation that will describe this dependence will have the following form:

$$Y2 = -60.6811-0.4867\,V+30.41\,H+0.6167\,V^2+0.09\,V\,H-1.6633\,H^2. \qquad (19)$$

– coefficient of variation of the depth of sowing of barley seeds:

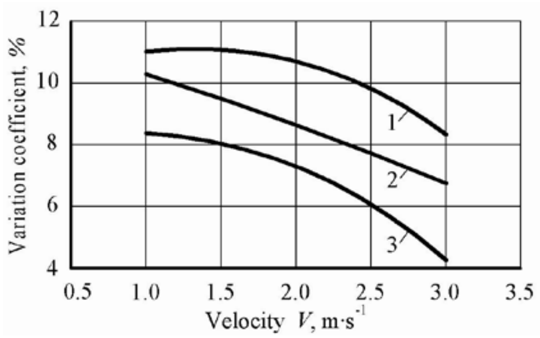


Fig. 6. Effect of the forward speed of the fertilizer-seeding unit on the variation coefficient of the depth of sowing of barley seeds at a different depths of seed sowing: 1 – H = 2 cm; 2 – H = 4 cm; 3 – H = 6 cm

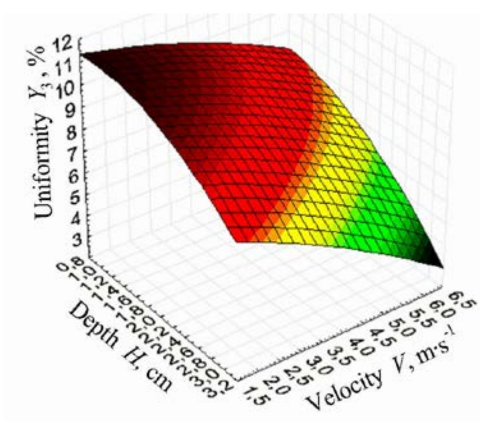


Fig. 7. Effect of forward speed of the fertilizer-seeding unit and the depth of sowing of seeds on the response surface of the dependence of the coefficient of variation of the seeding depth of barley seeds

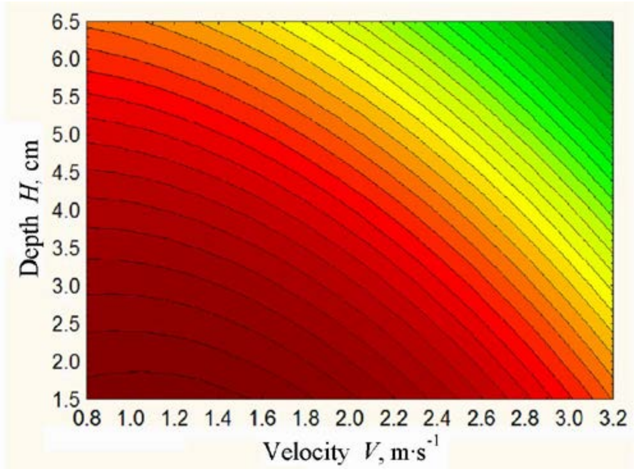


Fig. 8. Effect of the forward speed of the fertilizer-seeding unit and the depth of sowing of seeds on the two-dimensional cross-section of the coefficient of variation of the depth of sowing of barley seeds

The analysis of the results obtained (Figures 6, 7, 8) made it possible to determine the decrease in the deviation of the depth of seed sowing from the set value and the depth of sowing of seeds with increasing speed of movement.

The functional dependence for this case will have the following form:

$$Y3 = 10.79+1.7883\,V-0.05\,H-0.705\,V^2-0.18\,V\,H-0.055\,H^2. \quad (20)$$

When carrying out comparative field experimental studies of the quality of barley sowing with basic and modernized sowing units (aggregates), the following values of qualitative indices were obtained according to the adopted methodology:

– coefficient of seed depth variation for the basic unit was 8.2%, and for modernized unit was 4.7%;

– uniformity of seed distribution along the row length for the basic unit was 63.8%, for the modernized unit was 84.9%;

– field germination of seeds when sowing by the basic unit was 80.4%, for modernized unit was 87.4%.

So, based on the analysis of the results of the research results, it is established that when the combined seeding machine is used, the uniformity of seed distribution along the length of the row will be substantially increased. Simultaneously, the field germination of the seeds will increase, and the coefficient of variation in the depth of seed placement in the furrow will decrease. The obtained data of experimental studies confirm the improvement of the quality of sowing when combining technological operations with a combined sowing unit. At the same time, it was established that in the process of the combined unit operation in the field conditions, there could be flaws in the mutual arrangement of the rows of passes of the two seeders of the unit due to the imperfect construction of the coupling.

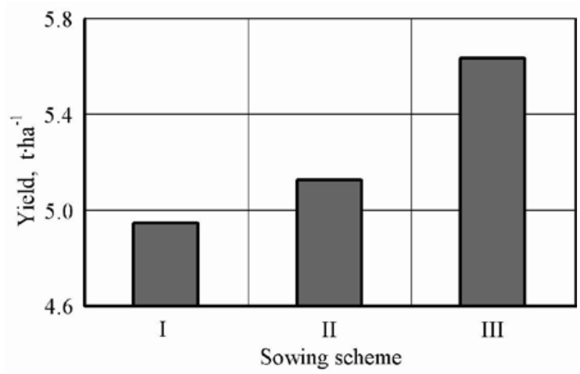
Experiments were conducted to justify the expediency of combining the above technological operations in one pass of the unit (aggregate). For this purpose, the research areas on which spring wheat and spring barley were sown within experiments which was divided into three main schemes:

1) sowing of grain crops after cultivation without applying fertilizers (control = scheme I);

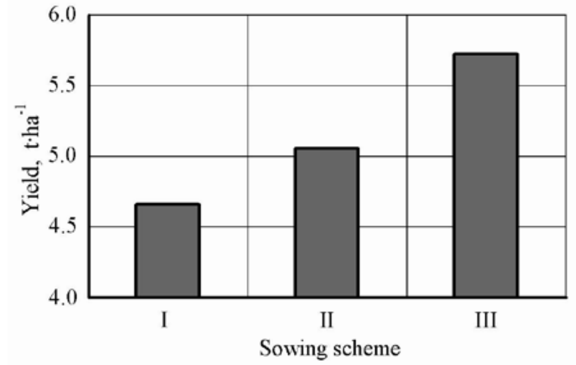
2) continuous introduction of a starting dose of mineral fertilizers in a dispersed way + pre-sowing cultivation + combined sowing with simultaneous application of the basic rate of fertilizers (scheme II);

3) pre-sowing cultivation + combined sowing by the experimental seeding unit with simultaneous application of the starting and basic fertilizer rate (scheme III).

Also, studies were carried out to evaluate the yield increase when applying a modernized seeding unit in comparison with conventional pre-sowing soil without applying granular mineral fertilizers and with a continuous superficial application of the starting fertilizer dose, with further pre-sowing soil cultivation and sowing of seeds, while simultaneously introducing the main dose of fertilizers into the soil. As a result of the studies (Figure 9) it was received an information that when using a combined seeding machine for simultaneous sowing with the introduction of the starting and basic fertilizer doses, the yield of spring wheat is 5.64 t·ha^{-1} and spring barley 5.73 t·ha^{-1}.



a)



b)

Fig. 9. The diagrams presenting the yield of grain of spring wheat (a) and spring barley (b) when sowing according to schemes: I, II and III

In this case, compared with the application of a full-area fertilizing of the fertilizer starting rate in a spreading method, pre-sowing cultivation and combined sowing with the simultaneous introduction of the basic fertilizer rate, the yield of spring wheat was increased by 0.51 t·ha^{-1} and spring barley by 0.67 t·ha^{-1}. The increase in yields when using the modernized aggregate in comparison with sowing without fertilization is 0.69 t·ha^{-1} for spring wheat and 1.06 t·ha^{-1} for spring, respectively.

Taking into account the price of 1 metric centner of grain crops (as of January 2017), the economic effect of increasing the yield of grain crops for spring wheat is 2652.00 UAH·ha^{-1}, and for spring barley is 3048.50 UAH·ha^{-1}.

Table 1 Technological and operational parameters of the combined seeding unit

Parameter	Value
Turning radius, m	6.5 – 8.9
Duration of the turning, s	18.4 – 24.7
Average forward speed on the headland, m·s^{-1}	1.78
Deviation of the trajectory of the second machine relative to the trajectory of the first machine, cm: when turning during the working pass	 23.7 3.6
Specific fuel consumption, lt.·ha^{-1}	3.77
Shift time utilization coefficient	0.85

When conducting field studies using the standard method, the shunting and operating parameters of the combined seeding unit (Table 1) were also determined, which confirm the compliance of these indicators with the requirements for effective sowing.

According to the analysis of the obtained results of field studies of the work quality indicators, as well as the evaluation of the increase in the yield of cereals due to the application of the combined seeding unit, the expediency of combining the technological operations of sowing grain crops with the introduction of the starting and the main fertilizer dose in one pass of the proposed combined seeding unit has been proved.

4. Conclusions

As a result of field experimental studies, an increase in the yield of spring wheat and spring barley was confirmed with the use of a combined seeding machine for simultaneous sowing of cereal crops with application of a starting and basic dose of fertilizers into the soil in comparison with known sowing schemes. The obtained results of field research confirm the expediency of combining the technological operations of sowing seeds of cereal crops from the intra-soil application of the starting and basic norms of fertilizers in one pass of the combined seeding unit.

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