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EVALUATION OF WINTER RAPE FOLIAR FERTILIZATION SYSTEM USING CHLOROPHYLL FLUORESCENCE PARAMETERS

***S.E. AMONS**, Candidate of Agricultural Sciences, Associate Professor Vinnytsia National Agrarian University*

Over the course of two vegetation seasons of winter rape cultivation, a comprehensive assessment of the fertilization effectiveness was carried out for various foliar fertilization options using complex chelated micronutrient fertilizers at the budding stage. An innovative physiological indication method was applied, based on the induction of chlorophyll fluorescence with detailed analysis of the Kautsky curve and determination of its core parameters such as F0 – minimal (initial) fluorescence, Fpl – fluorescence induction 'plateau' value, Fm – maximal fluorescence, Fst – steady-state fluorescence, as well as nine derived indicators calculated on their basis within a unified methodological analysis cycle.

Graphical interpretation of the results was carried out with the construction of averaged chlorophyll fluorescence induction (CFI) graphs for each variant of micronutrient fertilizer application. A summary table of derivative indicators based on the standard European protocol for chlorophyll fluorescence analysis was compiled, emphasizing its importance for evaluating the physiological condition of plant organisms.

It was determined that winter rape plants exhibit a distinct response to the optimization of mineral nutrition conditions, including foliar fertilization systems. This allows the identification of the optimal variant both in terms of predicted productivity increase and enhancement of plant adaptability and stress resistance, as well as development of an efficient photosystem and realization of the plant's genetic potential.

It was found that various micronutrient fertilizers significantly affect photosystem activity and its efficiency, with a range of 5.5% to 26.4% among the tested fertilizers. This provides grounds for identifying specific types and subtypes of fertilizers based on nutrient ratios and chemical composition. Based on this comprehensive evaluation, it was concluded that among the three tested micronutrient fertilizers—Avangard Rape, Yarilo Oilseed, and Helprost Rape—the application of Helprost Rape demonstrated the highest physiological efficiency in supporting the functioning of the assimilation surface and improving plant stress resistance and adaptability.

***Keywords:** winter rape, chlorophyll fluorescence, micronutrient fertilizers, foliar feeding, stress resistance, adaptability.*

Tabl. 2. Lit 15. Figs. 2.

Problem Statement. The development of an effective fertilization system for growing agricultural crops is a key condition for realizing their genetic potential. This is especially important for winter rapeseed, where the problem of efficient and sustainable cultivation remains relevant [1].

Despite the variety of approaches to modeling mineral nutrition optimization, there are many different ways to assess the effectiveness of fertilization. This includes both determining the results of the process and selecting appropriate norms and methods for fertilizer application [2]. The problem is further complicated by the presence of various forms of mineral fertilizers and methods of their application, as well as their marketing modifications aimed at covering key markets based on norms, timing, cost, and profitability [3].

The main method used to determine the overall effectiveness of the fertilization system is the yield level and the quality of the produced crop. However, the use of this criterion has certain limitations in terms of the critical factor at the end of the crop's vegetative period, which does not allow for timely intervention to adjust the fertilization system and create leverage for altering the variable part of fertilizer usage [4].

The second approach in evaluating fertilization is innovative and aims to clearly identify the effectiveness of the applied fertilization system based on monitoring the physiological condition of the plants before the fertilization process and throughout the entire period of implementing the applied fertilizer dose. This approach is based on systematizing the morphological indicators of plants within a comprehensive evaluation of their vitality strategy, which involves forming complementary systems of interaction between the dimensions of individual parts or the plant as a whole, depending on planting density and the level of additional mineral nutrition [5].

At the same time, for winter rapeseed, which develops in two cycles – autumn and spring – with a critical overwintering period that poses a real threat to achieving an appropriate level of yield, the effectiveness of mineral nutrition can be determined by the success of overwintering [6] and the physiological condition of the plants before entering winter and after the resumption of vegetation, which again depends on the fertilization system [7]. However, weather conditions sometimes prevent the timely diagnosis of plant status using the aforementioned set of morphometry or accurately assessing the physiological condition based solely on external signs [8].

In this regard, global science continues to apply physiological methods for evaluating plant responses to fertilization and its effectiveness in terms of forming an effective growth and development system. One such mechanism is the assessment of the effectiveness of applied additional mineral nutrition based on the well-known and universal process for higher plants, known as chlorophyll fluorescence induction, which is based on the fundamental principles of the functioning of the corresponding levels of the plant's photosystem. This serves as a basic indicator for evaluating different fertilization options [9].

At the same time, despite the fundamental nature of this issue, the problem of chlorophyll fluorescence has many unexplained aspects when applied to major agricultural crops, particularly winter rapeseed. In this regard, studying the potential use of this physiological indication method to assess the fertilization system of winter rapeseed, based on a scientific and production evaluation system, remains an important task that requires further scientific generalization.

Analysis of Recent Research and Publications. The methodology of chlorophyll fluorescence is a well-known physiological process in the plant's photochemical reaction system, the intensity and course of which depend on the level of environmental stress, the genotype characteristics of the plant organism, and the physiological condition of the plants caused by pathogens, pest damage, toxicological reactions to heavy metals, radionuclides, and chemical pollutants, as well as limitations in the availability of basic soil mineral nutrients [10].

Despite the physiological and biological universality of this plant state research method and their response to stimuli and factors of various natures, the method has many controversial aspects, especially when applied to evaluating the completeness of soil nutrition systems for plants, considering critical phenological phases and in interaction with the optimal hydrothermal conditions during the vegetative period [9, 11].

A positive aspect of using the chlorophyll fluorescence induction method is the presence of a clear indication graph of the plant's reaction (the so-called Kautsky curve), the parameters of which are used to assess the general condition or stress level of the plant organism by evaluating the photosystem of its assimilation surface in the active leaf apparatus layers. At the same time, the effectiveness of chlorophyll fluorescence intensity (CFI) studies helps to expand understanding of the regulatory mechanisms that ensure effective energy conversion during the primary and subsequent stages of photosynthesis [12].

From the perspective of applying this method to assess the effectiveness of both basic fertilization and, importantly, foliar feeding options, which directly affect the kinetics of photochemical reactions in the leaves of plants in the active physiological layer [12], changes in the shape of the Kautsky curve and the formation of a set of indicators to signal relevant reactions, including those to components and forms of additional mineral nutrition during the vegetation period of the crop, are critical.

It is emphasized [9, 13] in the context of the outlined issues that clarifying the features of the plant photosystem's response to the application of mineral fertilizers and various growth-stimulating components is a controversial topic. Ultimately, this highlights the importance of our research and contributes to the improvement of physiological tactical approaches to assessing the effectiveness and appropriateness of the fertilization system for winter rapeseed, based on clear physiological mechanisms of stress responses throughout the entire plant organism. This approach will allow for the evaluation of the effectiveness and appropriateness of applying different fertilization options for the crop and ensure the economic feasibility of their use, considering the growing cost of agrochemicals.

Conditions and Methodology of the Research. The research was conducted over two vegetative seasons of winter rapeseed (2022/2023 and 2023/2024) at the "ZORYA VASYLIVKY" farm in the village of Tyvriv, Tyvrivskyi district, Vinnytsia region. The soil cover of the farm was represented by gray podzolized, medium loamy sands on loess, which are typical for the agro-soil zoning of the central regions of Vinnytsia.

The agrochemical parameters of the soil cover in the experimental plots were as follows: pH (H_2O) – 5.8–6.0; humus content (according to Tyurin) – 2.15%, easily hydrolyzable nitrogen (according to Cornfield) – 80.5 mg, exchangeable potassium and available phosphorus (according to Chirikov) – 119 and 102 mg per 1 kg of soil, respectively. Hydrolytic acidity was 9.9 mg eq. per 1 kg of soil; the sum of absorbed bases was 224 mg eq. per 1 kg of soil, and base saturation was 83.7%.

The research was established and conducted on the high-intensity hybrid of winter rapeseed, DAX CL (produced by "DSV").

DAX CL is characterized by active autumn development and is suitable for late sowing dates, which significantly extends the sowing window for rapeseed. At the same time, the hybrid exhibits rapid regeneration after winter and early flowering, which is especially important for continental climate conditions and optimal use of moisture reserves. Thanks to its strong root system, drought resistance, and compensatory potential, DAX CL demonstrates stable and high results even under the most challenging conditions. Additionally, its medium-maturity group and resistance to pod shattering ensure uniform ripening and harvesting without losses. The DAX CL hybrid combines a full set of important agronomic characteristics that greatly expand the possibilities for growing winter rapeseed, especially in short-rotation crop rotations and soils with a high potential for weed infestation.

The hybrid is characterized by high resistance to major diseases and pests (average rating of 8.4) and a high yield potential of up to 5 t/ha under intensive cultivation practices.

The weather conditions during the vegetation periods of the 2022/2023 and 2023/2024 seasons were generally assessed as satisfactory for the growth and development of winter rapeseed plants. A prolongation of interphase growth periods was observed during the spring regrowth phase due to unstable moisture availability. During the 2023/2024 vegetation season, accelerated ripening of the plant's reproductive elements was recorded, caused by elevated temperatures combined with a moisture deficit in June–July. Extremely low temperatures during the research period were recorded at the end of December through the second ten-day period of January, reaching -11.7 °C in the 2022/2023 season and -10.9 °C in the 2023/2024 season. These conditions did not pose a threat to the overwintering of the plants or their ability to resume vegetation in the spring. The moisture regime for winter rapeseed during the study period was characterized as unstable, particularly during April–May and June–July in both vegetation seasons.

The research program included the study of the physiological response of winter rapeseed plants to the application of various foliar feeding systems, based on the analysis of chlorophyll fluorescence processes after application. The scheme and variants of the agrochemical treatment system are presented in Table 1. The experiment was conducted using a four-replication design with a systematic arrangement of treatments in two tiers. The total area of the accounting plot was 50 m². In both growing seasons, winter rapeseed was sown in the first ten days of September at a seeding rate of 500,000 seeds/ha with 35 cm row spacing. Post-sowing rolling was performed after seeding. The crop management system for winter rapeseed across all treatment variants was uniform and included the following: at the 2-leaf stage, the herbicide *Butizan Avant* (2.5 L/ha) was applied; five days later,

Table 1

Experimental design for studying the physiological response of winter rapeseed to foliar fertilization variants based on the criterion of chlorophyll fluorescence against the background fertilization of $N_{90}P_{60}K_{60}$, 2022–2024

№	Application variant	Application rate
1	Application variant	–
2	At the budding stage, in addition to the background, micronutrient fertilizer *Avangard Rapeseed*	2 l/ha
3	At the budding stage, in addition to the background, micronutrient fertilizer *Helprost Rapeseed*	2 l/ha
4	At the budding stage, in addition to the background, micronutrient fertilizer Yarylo Oilseed	2 l/ha

source: formed on the basis of own research

Killitop (1.5 L/ha) (cypermethrin 50 g/L + chlorpyrifos 500 g/L) was used against cutworm species, along with the insecticide *Instryker* (0.2 L/ha) at the 7–8 leaf stage. After the resumption of vegetation, treatments were applied against a complex of diseases and pests: *Derosal* (carbendazim 500 g/L, 1 L/ha) and *Evans* (0.15 L/ha). During the budding stage, *Clark* (0.4 kg/ha), *Veto* (0.5 L/ha), and *Instryker* (0.2 L/ha) were applied, and at mid-flowering, treatments against the rapeseed blossom beetle included *Pictor* (0.4 L/ha) and *Biscaya* (0.5 L/ha).

The preceding crop in all treatments was winter wheat. Soil tillage after harvesting the previous crop included preliminary double-pass disking to a depth of 6–8 cm, followed by plowing with leveling to a depth of 22–24 cm.

The selected foliar fertilization treatments were applied during the budding stage of winter rapeseed, using a working solution volume of 250 L/ha for all fertilization variants.

A brief description of the applied micronutrient fertilizers, based on information from the official distributors' websites, is provided below.

Helprost Rapeseed. Contains (g/L up to): macronutrients (P – 48,375; K – 54,875); mesoelements (S – 27,95; Mg – 26,96); micronutrients (B – 12,9;Zn – 5,375;Fe – 1,6125;Mn – 21,5;Cu – 4,3;Mn – 21,5); biologically active substances: amino acids 10,75; vitamins 0,1075; peptides – 5,375; polysaccharides – 0,5375.

Avangard Rapeseed. A fertilizer intended for foliar feeding (spraying) of winter rapeseed crops during the growing season. Treatment during vegetation is recommended in combination with biopreparations or plant protection products. Application rate: 1.0–3.0 L/ha.

It contains a balanced ratio of macro-, meso-, and micronutrients. Composition of the micronutrient fertilizer: N – 60; K_2O – 10; SO_3 – 121; MgO – 50; Fe – 4; Mn – 10; Cu – 4; Zn – 7; B – 6; Mo – 0,1; Co – 0,1. Micronutrients: Mn, Zn, Cu chelated with EDTA (ethylenediaminetetraacetic acid); Fe is chelated with DTPA (diethylenetriaminepentaacetic acid).

Yarylo Oilseed. A concentrated complex fertilizer with a balanced content of macro- and micronutrients tailored to meet the needs of oilseed crops. The chemical composition of Yarylo Oilseed includes: carboxylic acids, humates, surfactants, total N – 34, MgO – 24, SO_2 – 1, Fe – 10, Mn – 10, B – 5, Zn – 1.5, Cu – 0.15, Mo – 0.004. It contains a well-balanced amount of nutrients in a plant-available form, ensuring complete absorption. The fertilizer enhances plant yield, is compatible with most pesticides (allowing integration into crop protection systems), spreads evenly over the leaf surface, and is resistant to being washed off by precipitation. It is non-phytotoxic and safe for humans and beneficial entomofauna.

To assess chlorophyll fluorescence parameters, the domestically produced portable fluorometer "Floratest" was used, applying the standard measurement method with a total measurement duration of 3 minutes and a fluorescence response curve recorded over a 90-second interval [14]. The measurements were taken from leaf blades with a total exposure time of 3 minutes. Leaves were assessed at the beginning of flowering (BBCH 64–65), specifically 10–12 days after foliar feeding was applied. For treatments without foliar feeding and those with only background mineral fertilization, measurements were taken on the same date corresponding to the outlined phenological phase. Prior to measurement, the leaves underwent a dark adaptation period of 10 minutes using a light-proof isolator. The number of leaves analyzed in each treatment was no less than 25.

In the system for processing the recorded indicators, the key points of the chlorophyll fluorescence index (CFI) curve (Fig. 1) were analyzed [9]: F_0 – minimal (initial) fluorescence,, F_{pl} – "plateau" level of fluorescence induction, F_m – maximum fluorescence, F_{st} – steady-state fluorescence.

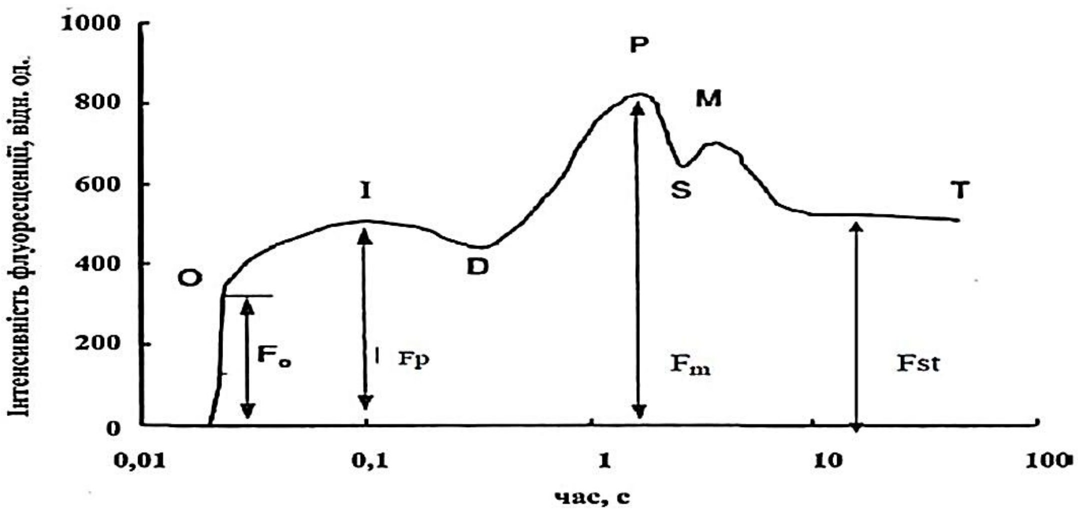

Figure 1. Basic model of the CFI curve: F_0 – minimum (initial) fluorescence, F_{pl} – plateau level of fluorescence induction, F_m – maximum fluorescence, Fst – steady-state fluorescence [9].

The complete set of calculated parameters of the CFI curve is summarized in Table 2. A classical analysis of variance (ANOVA) scheme was applied to the obtained average values of the indicators, with significance determined using the LSD test at a significance level of $p < 0.05$.

Table 2

Calculated Indicators Based on the Basic Constants of the CFI Curve (compiled and summarized from [5])

CFI Curve Indices	Formulas for Calculation
Fluorescence Rise	$dF_{pl} = F_{pl} - F_0$
Maximum Variable Fluorescence	$F_v = F_m - F_0$
Index of Exogenous and Endogenous Factor Influence	$\frac{dF_{pl}}{F_v}$
Photochemical (Quantum) Efficiency (EP)	$EP = \frac{F_v}{F_m}$
Photochemical Quenching (Q_{ue})	$Q_{ue} = \frac{F_0}{F_v}$
Leaf Water Potential (L_{wp})	$L_{wp} = \frac{F_m}{F_0}$
Plant Vitality Index (RF_d)	$RF_d = \frac{F_m - F_{st}}{F_{st}}$
Indicator of Endogenous (Stress) Factors (K_{ef})	$K_{ef} = \frac{F_{st}}{F_m}$
Magnitude of Photochemical Quenching of Fluorescence (QP)	$QP = \frac{F_m - F_{st}}{F_m - F_0}$
Primary Photosynthesis Reaction Efficiency Index (K_{prp})	$K_{prp} = \frac{F_v}{F_0}$
Fluorescence Quenching Coefficient (K_{fd})	$K_{fd} = \frac{F_m}{F_{st}}$
Relative Fluorescence Change at Time t (V_t)	$V_t = \frac{F_{st} - F_0}{F_m - F_0}$

Presentation of the main research material. According to the results of using a portable fluorometer, it was determined that the photosystem of winter rapeseed plants had a physiological sensitive indication reaction to the application of additional foliar feeding. These conclusions are confirmed by the characteristics of the Kautsky curve obtained as a result of the implementation and processing of the results of measurements of chlorophyll fluorescence induction on the active assimilation surface (leaf) after its dark preadaptation (Fig. 2). The presented curves had significant ordinate differences in the main basic key indicators of the curve in the context of the applied feeding options, which differed in the type of microfertilizer taken for feeding. Such an experimental system allowed us to identify the degree of sensitivity of the photosystem of winter rapeseed plants to changes in the nature of the active substance of a particular microfertilizer and to assess the effectiveness of this method from a physiological point of view in selecting optimal fertilization options.

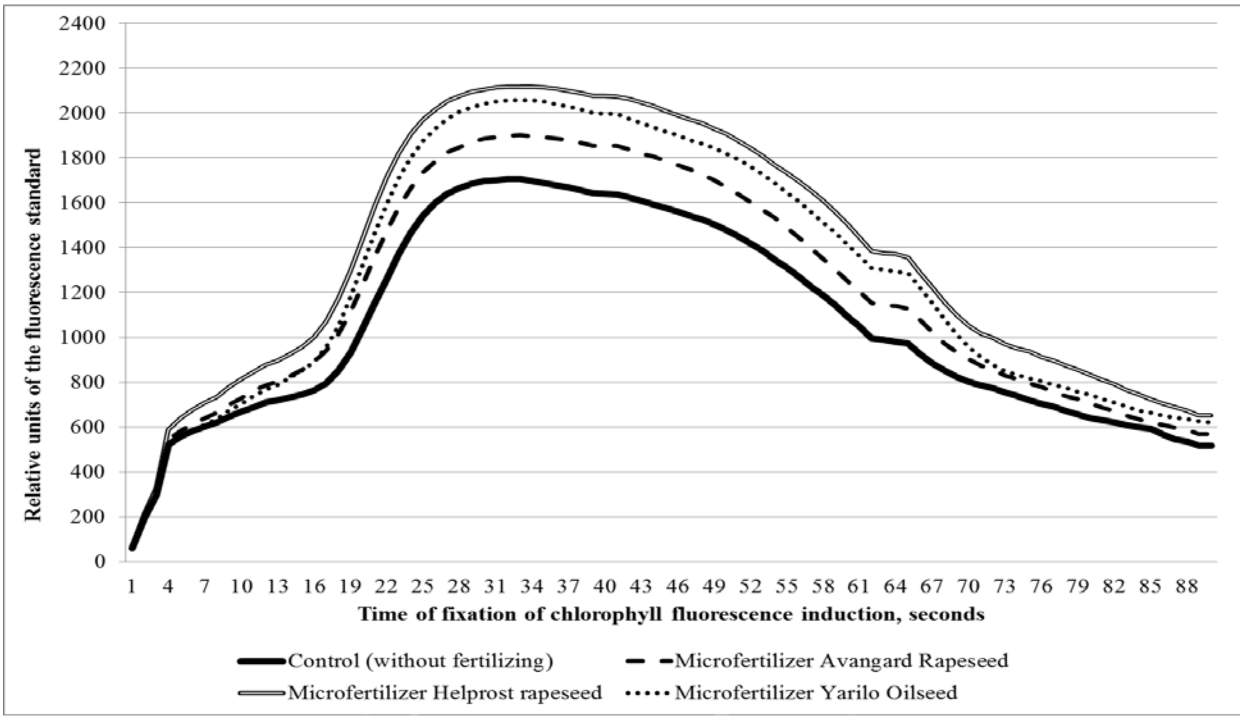

Fig. 2. The nature of the chlorophyll fluorescence induction curve depending on the system of fertilization for the budding phase (BBCH 59-61) (average for the period 2023-2024)

source: formed on the basis of own research

It was also found that all the basic components of the CFI Curve ((F_0, F_{pl}, F_m, F_{st}) had a variable nature depending on the type of microfertilizer. Thus, in comparison with the control, the application of the microfertilizer Helprost rapeseed provided the formation of the highest area of the graph in the interaction of the abscissa and ordinary directions. At the same time, the control had the smallest given indicator. As a result, the ratio of the active area of the graph above the abscissa of the applied microfertilizers in relation to the control on average over the research period was in the increase of 11.8% for the microfertilizer Avangard rapeseed, 29.7% for the microfertilizer Yarilo Oilseed and 41.7% for the microfertilizer Helprost rapeseed. Considering the research [11], they indicate a high level of dependence between the activity of the photosystem of a given plant species and the nature of a particular microfertilizer.

These conclusions are in positive agreement with the results of accounting for the basic indicators of the IFC curve and the derived calculation indices determined on their basis, the average values of which are presented in the form of Table 3.

Applying the standard protocol for analyzing the FTIR curve parameters [9-11], we will analyze the data obtained. Given that the F0 index is determinant in assessing the overall efficiency of the reaction centers of the plant photosystem, its lower value in the graph and table indicates a general slow reaction of the reaction centers to the transmitter system of energy flows of redistributed photosynthetic radiation [5]. At the same time, its value was minimal in the control and significantly different in

Table 3

Basic and calculated indicators of the IFH curve depending on the options for applying fertilizer to winter rapeseed during the budding phase (BBCH 59–61) (average for 2023–2024 in relative units of the fluorescence standard)**

Application variant	F_0	F_{pl}	F_m	F_{st}	dF_{pl}	F_v	dF_{pl}/F_v	EP
Control (without fertilizing)	435	670	1706	515	235	1271	0,185	0,745
At the budding stage, in addition to the background, micronutrient fertilizer *Avangard Rapeseed*	459	685	1899	568	226	1440	0,157	0,758
At the budding stage, in addition to the background, micronutrient fertilizer *Helprost Rapeseed*	479	690	2117	652	211	1638	0,129	0,774
At the budding stage, in addition to the background, micronutrient fertilizer Yarylo Oilseed	474	678	2057	621	204	1583	0,129	0,770
Application variant	L_{wp}	Q_{ue}	RF_d	K_{ef}	**QP**	K_{prp}	K_{fd}	V_t
Control (without fertilizing)	3,92	0,342	0,678	0,302	0,937	2,922	3,313	0,063
At the budding stage, in addition to the background, micronutrient fertilizer *Avangard Rapeseed*	4,14	0,319	0,701	0,299	0,924	3,137	3,343	0,076
At the budding stage, in addition to the background, micronutrient fertilizer *Helprost Rapeseed*	4,42	0,292	0,718	0,308	0,894	3,420	3,247	0,106
At the budding stage, in addition to the background, micronutrient fertilizer Yarylo Oilseed	4,34	0,299	0,698	0,302	0,907	3,340	3,312	0,093
LSD_{05} F_0	A 4,50; B 3,59; C 3,59; D 5,45; AB 6,88; AC 6,88; AD 10,10; BC 5,45; BD 8,08; CD 8,08; ABC 10,10; ABD 14,66; ACD 14,66; BCD 11,81; ABCD 21,11							
F_{pl}	A 4,96; B 3,88; C 3,88; D 5,86; AB 7,38; AC 7,38; AD 10,82; BC 5,86; BD 8,67; CD 8,67; ABC 10,82; ABD 15,67; ACD 15,67; BCD 12,63; ABCD 22,53							
F_m	A 16,77; B 13,52; C 13,52; D 19,50; AB 24,08; AC 24,08; AD 34,43; BC 19,50; BD 27,95; CD 27,95; ABC 34,43; ABD 49,07; ACD 49,07; BCD 39,90; ABCD 69,76							
F_{st}	A 3,20; B 2,44; C 2,44; D 3,83; AB 4,89; AC 4,89; AD 7,29; BC 3,83; BD 5,79; CD 5,79; ABC 7,29; ABD 10,68; ACD 10,68; BCD 8,56; ABCD 15,48							

* – year conditions were used as an additional factor in the dispersion system of the experiment.
source: formed on the basis of own research

different variants of microfertilizers application. Thus, the increase in F_0 compared to the control was 5.5% when using Avangard Rapeseed micronutrient for fertilizing, 10.1% when using Helprost Rapeseed micronutrient and 8.5% when using Yarylo Oilseeds fertilizer.That is, the influence of foliar fertilization options is identified at the initial stage of the chlorophyll fluorescence process. This nature of the formation of the indicator has been noted in a number of studies [5, 12, 13, 15] and forms an instrumental potential for the selection of the optimal fertilizer option at the early stages of the reaction of the assimilation surface to foliar foliar feeding. It is also known that F_{pl} (fluorescence of the plateau zone) is an indicator of the intensity of signal transmission of the plant photo system in the general chain that combines the reaction centers of photoplasts [9]. In physiological terms, this indicator demonstrates the rate of decay of such transmission and its prolonged value at the stagnation point indicates both the reduced physiological activity of this assimilation surface and negative reactions to the irritant component, which can be fertilizers themselves. Therefore, a higher value translates the overall efficiency of photochemical reactions to a different level of attenuation. At a higher value of F_{pl}, the intensity of the growth of the IFH curve occurs in a different response format. In our case, the use of fertilizers in general contributed to the growth of the indicator in the range of 1.25-4.15% with a maximum in the variant of using Helprost oilseeds microfertilizer.

An important indicator that demonstrates the overall energy efficiency of the plant photosystem is the level of maximum achievable fluorescence Fm. It is decisive in calculating the coefficients of use of the FAR and the efficiency of its transformation into synthesized substance. Its value has a positive high correlation in the composition of the dark phase of donor-acceptor transformations in photosynthesis [10]. It should be noted that the use of foliar fertilizers had a significant incremental effect on its formation with the following character: from the use of Avangard Rapeseed microfertilizer, 13.1% for the use of Helprost Rapeseed microfertilizer and 24.1% and for the use of Yarylo Oilseeds fertilizer 20.6%. The increase in the maximum fluorescence level according to [5, 15] indicates an overall optimization of the intensity of photosynthetic reactions, which ultimately contributes to a higher efficiency of transformation of the energy consumed by the photo system into biosynthesis of additional yield.

The generalizations made also positively correlate with another important basic parameter of the CFI curve, F_{st}. This parameter is an integrating characteristic of the rate of decay of photochemical reactions of the photosystem and determines the overall rate of its response to optimization or, conversely, the stressful effect of individual technological factors [10]. An increase in this indicator indicates an inhibition of the outflow of reduced photoproducts from reaction centers due to unfavorable environmental factors [9]. It was proved that the value of this indicator depended on the fertilization option. In general, the nature of this effect was marked by a general increase with the rise of the final links of the CFI curve according to the ordinal value of the value of the conditional reference fluorescence units. In particular, when applying Avangard Rapeseed micronutrient, the indicated increase to the control was 10.3% when using Helprost Rapeseed micronutrient and 26.6% when using Yarylo Oilseeds 20.6%. The closeness of the incremental values from the effect of fertilization for F_0 and F_{st} demonstrates the sensitivity of the decline area in the interval from the maximum to the minimum value determined in winter rape with alternative estimates of the photo system response [15].

Another important aspect of the chlorophyll fluorescence method is that its basic indicators can be transformed through a system of indices into important identifying physiological characteristics. In particular, such an indicator as L_{wp} is a reflection of the water potential of the leaf apparatus and largely determines the resistance of the assimilative active surface of middle-tier plants to the conditions of legalization of weather conditions from the point of view of deterioration of hydrothermal regimes [5]. Based on this, the use of foliar fertilization had a positive effect on this adaptive effect of assimilation of winter rape plants with an increase to the control in the range of 5.5-12.7% with a maximum when using Helprost rape microfertilizer in fertilization.

Another indicator RF_d, which is an indicator of the level of vitalization of the agrophytocenosis of the corresponding plant species [11] and can be used to assess the effectiveness of pre-sowing design of crops of the corresponding crops at the stage of critical phenophases, also had a positive growth dynamics in comparison with the control, again with a maximum increase of 5.9% when applying the microfertilizer Helprost rape. Based on this, the optimization of the foliar nutrition system of winter rape can be used for the combined optimization of the density and feeding area of rape plants by adjusting the care measures during the formation of reproductive fruit elements of the crop.

It was also determined that due to the decrease in the rate of quantum quenching of chlorophyll fluorescence induction (measured by Q_{ue}) in the dynamics during the research period with a decrease in the range of 6.9-14.6%, it forms accelerated processes of metabolism and accumulation of formed organic matter, which minimizes agrotechnological risks in planning the sowing dates and adaptive potential of the corresponding genotypes of winter rape. These conclusions are confirmed by the results of the evaluation of the relative change in fluorescence at time t (V_t) with the growth index from the use of foliar fertilization in comparison with the control 1.20-1.68 with a maximum in the variant of using the microfertilizer Helprost rape.

In the end, based on the values of the indicative calculated indicators that determine the overall level of abiotic stress pressure on the assimilation surface of plants (L_{wp}, RF_d, K_{prp} and K_{fd} [9]), it was proved that in general, the use of foliar mineral nutrition in combination with macro- and microelements increases the physiological adaptability of the plant organism and reduces stress, which will positively affect the formation of winter rape plant productivity.

Conclusions and prospects for further research. Taking into account the obtained results and the identified dependencies, the possibility of using the chlorophyll fluorescence tools with a complex of basic (F_0, F_{pl}, F_m, F_{st}) and derived criteria of the CFI curve to identify the optimality and effectiveness of the application of the foliar feeding system of winter rape in the combined fertilization options was confirmed. In particular, according to the results of a multi-year cycle of evaluations among the applied three micronutrient fertilizers to the background mineral nutrition, the effectiveness and feasibility of using the micronutrient Helprost rape in the form of foliar feeding for the budding phase (BBCH 59-61) at a rate of 2 l/ha was established, which contributes to the overall optimization of photochemical transformations in the plant photo system and increase the overall stress resistance and abiotic adaptability of plants under these variants of sowing time and method.

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АНОТАЦІЯ
ОЦІНКА ЕФЕКТИВНОСТІ СИСТЕМИ ПІДЖИВЛЕННЯ РІПАКУ ОЗИМОГО ЗА ПАРАМЕТРАМИ ФЛОУРЕСЦЕНЦІЇ ХЛОРОФІЛУ АКТИВНОГО ЛИСТКОВОГО АПАРАТУ

За два вегетаційних сезони вирощування ріпаку озимого проведено комплексну оцінку ефективності його удобрення у варіантах позакореневого живлення із застосуванням комплексних хелатних мікродобрив у фазу бутонізації. Для вказаної оцінки було застосовано інноваційний фізіологічний метод індикації, який базувався на методі індукції флуоресценції хлорофілу з детальним аналізом кривої Каутського та визначенням базових її параметрів таких як F_0 – мінімальна (початкова) флуоресценція, F_{pl} – величина «плато» індукції флуоресценції, F_m – максимальна флуоресценція, F_{st} – флуоресценція в стаціонарному стані та дев'яти похідних показників розрахованих на їх основі в єдиному методологічному циклі аналізу. Проведено графічну інтерпретацію отриманих результатів з побудовою усереднених *графіків ІФХ для кожного варіанту застосування мікродобрив у підживлення та сформовано зведену таблицю похідних показників типового європейського протоколу аналізу флуоресценції хлорофілу як важливого аспекту аналізу фізіологічного стану рослинних організмів. Визначено, що рослини ріпаку озимого мають чітку реакцію на оптимізацію умов мінерального живлення та застосування системи позакореневих підживлень зокрема, що дозволяє ідентифікувати оптимальний його варіант як з позиції прогнозованого зростання продуктивності агрофітоценозів культури, так і забезпечує підвищення адаптивності та стресостійкості самих рослин із формуванням ефективно діючої фото системи та реалізації генотипового потенціалу рослин.*

Встановлено що різні мікродобрива мають істотно різний вплив на діяльність фото системи рослин та її результативність з розмахом для вивчаємої сукупності мікродобрив на рівні від 5,5 до 26,4% що дозволяє ідентифікувати як окремі види добрив, так і їх підвиди спираючись на співвідношення у них елементів живлення та відповідного хімізму структури.

Узагальнено на підставі такого комплексного оцінювання, що серед трьох застосованих мікродобрив Авангард ріпак, Ярило Олійний та Хелпрост ріпак варіант із внесенням останнього мікродобрива продемонстрував найвищу фізіологічну ефективність у забезпеченні ефективного функціонування асиміляційної поверхні рослин та підвищення загальної стресостійкості та адаптивності рослин.

Ключові слова: *ріпак озимий, флуоресценція хлорофілу, мікродобрива, позакореневі підживлення, стресостійкість, адаптивність.*

Табл. 2. Рис. 2. Літ. 15.

Information about the author

Амонс Сергій Едуардович – кандидат сільськогосподарських наук, доцент кафедри ботаніки, генетики та захисту рослин Вінницького національного аграрного університету (21008, м. Вінниця, вул. Сонячна, 3, e-mail: sergeyamons@gmail.com).

Amons Sergey – Candidate of Agricultural Sciences, Associate Professor, Associate Professor of the Department of Botany, Genetics and Plant Protection, Vinnytsia National Agrarian University (21008, Vinnytsia, 3, Soniachna Str., e-mail: sergeyamons@gmail.com).