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Effect of Nitrogen Nutrition and Environmentally Friendly Combined Chemicals on Productivity of Winter Rapeseed under Global Climate Change

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Abstract: The research article presents the results of five-year field studies conducted in the conditions of the steppe zone on ordinary black low-humus soils (47.629, 32.079) to determine the productivity of winter rapeseed under the influence of early spring nitrogen nutrition in combination with environmentally friendly combined chemicals. Field experience was based on a three-factor scheme, where: factor A is early spring nutrition with nitrogen in a dose of N_{60}, N_{90} and without nutrition; factor B is foliar treatment of plants with Wuxal® and Helafit Combi® twice during the growing season of winter rapeseed and a control option-spraying of plants with pure water. Foliar treatments of winter rapeseed plants with chemicals were performed twice with a field sprayer: the first at the end of the second decade after the start of the resumption of spring vegetation; the second in the phase of the beginning of budding-flowering. The consumption rates of the chemical Wuxal Mikroplant® was 4.5 kg ha^{-1}, and Helafit Combi® was 1 l ha^{-1}; the outflow of working fluid is 250 l ha^{-1}. Factor C was the morphobiotypes of winter rapeseed: the *Chornii Veleten* variety, the originator of which is the Vinnitsya State Agricultural Research Station of the National Academy of Agricultural Sciences of Ukraine and the Kronos hybrid, the originator of which is seed company NPZ Lembke, Germany. Studies have established that the yield of various morpho-biotypes of winter rapeseed reaches its maximum when applying early spring nitrogen nutrition with a dose of N_{90} in combination with double application of foliar nutrition of plants with the combined growth-regulating chemical Helafit Combi®, the yield increase of the variety was 0.79 t ha^{-1}, and of the hybrid - 1.11 t ha^{-1}.

Keywords: Winter rapeseed, Yield, Early spring nitrogen nutrition, Foliar treatment, Growth-regulating chemicals

Modern climate changes affect all aspects of human life and agriculture in particular. Agrarians in the European Union are concerned about changes in crop conditions that have occurred over the past decades (Pichura et al 2019). Today's weather and climate transformations, increased soil erosion processes and a decrease in productivity growth rates pose a threat to the cultivation of field crops and global food security in the near future (Dudiak et al 2019, 2020). According to the forecasts of specialists of FAO of the OUN, with the constant course of events, almost 650 million people will suffer from hunger in the near future until 2030 (Russell 2017, Becker et al 2017). Global climatic changes both around the world and in the regions of Ukraine determine the search for and introduction of adaptive varieties and hybrids of field crops into agricultural production while improving their growing technologies in the context of the mandatory use of growth-regulating chemicals in the growing technologies. According to experts (Lisetskii et al 2016, 2017, Kipling et al 2019), we have a frequent further increase in air temperature, which will be accompanied by changes in dry periods with periods of normal and excessive moisture. Recent advances in genomics and agronomy can help alleviate some of the impacts of climate change on food production; however, given the timeframe for crop improvement, significant investment is required to realise these changes (Anderson et al 2020). The greenhouse effect leads to an increase in the temperature background, which, according to various information sources, in the last century was 0.5-0.7°C (Agovino et al 2019). An increase in carbon dioxide can change the photosynthesis of plants, and in combination with other factors, the nature of the production process. Changing environmental factors affect the signs of productivity of agrophytocenoses in time and space, therefore, the primary task is to solve the problem of preparing the agrarian complex in advance for these climate changes (Gosnell et al 2019). Such materials in harsh weather and climatic conditions can serve as a specific tool that optimizes the nutrition of agricultural plants, improves the absorption of macro-nutrients from the soil, mitigates the effects of drought stresses, manifestations of high temperatures, moisture deficiency, etc. (Bazaliy et al 2012, 2018).

In the dry steppes of Ukraine, one of the most influential stress factors is moisture deficiency. A number of scientists (Domaratskiy et al 2018, 2019) believe that it is impossible to achieve optimum moisture in the steppe zone; that this is a temporary situation, the duration of which fluctuates over a short time period. The rest of the growing season is stressful conditions that affect agrophytocoenoses with different intensities.In the technological chain of winter rapeseed growing, nitrogen nutritions and the application of growth-regulating chemicals are elements of spring plant treatments, and therefore, their influence is traced after the spring and summer vegetation. To form the optimal architectonics of plants in autumn before the cessation of autumn vegetation, which suppose the creation of a rosette with 8-10 leaves, rhizome up to 10 cm in diameter and a root neck diameter of 8-10 mm, winter rape consumes: up to 30% of nitrogen, 10% of phosphorus, 20% of potassium (in the first 4-6 weeks after sprouting), 25% of sulphur, 15% of magnesium, 25% of boron from the total need, while accumulating sufficient sugars and other plastic substances for wintering (Weymann et al 2015).

The root system assimilates the above elements differently during the growing season. Consequently, winter rapeseed plants in the initial stages of organogenesis absorb 20% of nitrogen, 10% of phosphorus, 20% of potassium and 10% of sulphur, in spring and summer - 67; 70; 80 and 65% and N - 13, P - 20, S – 25, respectively (Abramyk et al 2016). Compared to winter wheat, rapeseed removes more nitrogen - by 62%; phosphorus - by 66% and potassium - by 100%. During the formation of one ton of the yield, the seeds of winter rapeseed are absorbed from the soil up to 80 kg of nitrogen, 18-40 kg of phosphorus, from 25 to 100 kg of potassium, 30-150 kg of calcium and 35-40 kg of sulphur. Approximately, up to 25% of macro - and micro-nutrients (depending on the level of productivity) rapeseed can assimilate from soil reserves, the remaining necessary elements are provided by additional application of mineral fertilizers (Shcherbakov et al 2009, 2018). In case of violation of the optimal sowing terms, the level of risks significantly increases, leading to a decrease in the yield of winter rapeseed or a loss of the yield in general (Domaratskiy et al 2019). The authors note that winter rapeseed has a rather long period of a possible sowing with a change in risk from 10 to 80%.

With a high level of soil and air moisture deficiency during the sowing season and the initial stages of plant growth and development, there is a need to optimize nutrition processes and reduce the stress state of sowing to the minimum level. One of the promising ways for solving this problem is the use of inexpensive, but very effective elements of the technology for growing field crops, including obligingly foliar treatments of winter rapeseed plants with combined growth-regulating chemicals that are biological based and environmentally friendly. The use of such chemicals will allow to a certain extent to minimize the effect of stressful conditions on plants and, thereby, improve the absorption of macro- and micro-elements from the soil, optimizing the living conditions of the agrocoenosis as a whole. The purpose of the research is to evaluate the intensity of exposure to stress factors, which are quite often manifested in modern conditions of climatic change, as well as mitigate their negative impact due to nitrogen nutritions and growth-regulating substances and determine the effect of such substances of a multifunctional effect on winter rapeseed productivity.

MATERIAL AND METHODS

Field studies were conducted during 2012-2016. In the conditions of the steppe zone (coordinates: 47.629530, 32.079521) on ordinary black low-humus soils. Field experience was based on a three-factor scheme, where: factor A is early spring nutrition with nitrogen fertilizers in a dose of N_{60}, N_{90} and without nutrition; factor B is foliar treatment of plants with Wuxal® and Helafit Combi® twice during the growing season of winter rapeseed and a control option – spraying plants with pure water. Foliar treatments of winter rapeseed plants with chemicals were performed with an ОП-2000 field sprayer: the first - at the end of the second decade after the start of the resumption of spring vegetation; the second - in the phase of the beginning of budding-flowering. The consumption rates of the chemical Wuxal® was 4.5 kg ha^{-1}, and Helafit Combi® was 1 l ha^{-1}; the outflow of working fluid was 250 l ha^{-1}. Factor C was the morphobiotypes of winter rapeseed: the Chornii Veleten variety, the originator of which is the Vinnitsya State Agricultural Research Station of the National Academy of Agricultural Sciences of Ukraine and the Kronos hybrid, the originator of which is seed company NPZ Lembke, Germany. The experimental plots were arranged in three repetitions sequentially. The total sown area of the experimental plot was 2520 m^2, and the accounting area was 600 m^2. Sowing was carried out during the period of September 1-10 (depending on the conditions of soil moistening during the years of research) in drills (sowing distance was 15 cm) with a seeding rate of 1.0 million germinating seeds per ha. The predecessor was black fallow. Leaf area was calculated by the method of felling. The winter rapeseed yield was accounted for by a Class Dominator 96 combine equipped with a rapeseed harvesting device - a “rapeseed header table”.

RESULTS AND DISCUSSION

The main reagent for any factors of plant life is the leaf apparatus, which has a wide range of variation. The size of the leaf area should be at the optimum level, both underdeveloped and hypertrophic leaf surface is a negative phenomenon. In the case of underdevelopment of the leaf apparatus, a low index of the leaf surface adequately has a low level of photosynthetic productivity, and with hypertrophic development, an imbalance between the vegetative mass of plants and generative organs is observed. Plant growth, the formation of vegetative mass and generative organs is carried out due to the photosynthetic activity of the leaf apparatus. Photosynthetic activity is the main component of the formation of vegetative and generative organs in plants, which ultimately provides a certain level of productivity of crops. Photosynthesis is the process of formation of organic matter with the participation of solar energy and biochemical reactions in plant organisms. Chemical reactions occur only in the presence of a green pigment - chlorophyll. Chlorophyll-free photosynthesis is also known, but such a process is a feature of some lower organisms, this is not characteristic of higher green plants. The green pigment has a porphyrin structure, which in its structure is close to the blood heme of animals. The only difference is that heme has an iron (Fe), and chlorophyll has a magnesium (Mg) complex. About 75% of plant biomass is formed from carbon dioxide photo-fixation products from the atmosphere and only 25% from absorbed minerals. Plants are characterized by a close relationship in the metabolism between soil and air nutrition, and one process does not occur without the other. As a result of their interaction in the plant body, a series of successive reactions occur with the formation of carbohydrates, amino acids, proteins and fats. These substances directly form the crop yield (Domaratskiy et al 2019).

It is known that the intensity of photosynthesis is determined by the area of the assimilation surface of the leaves, which in turn depends on the growing conditions. That is why the size of the leaf surface and the duration of the intense activity of the leaves is the basis for determining the amount and intensity of accumulation of organic dry matter by plants. The level of plant productivity depends on three factors area of photosynthetically active leaf surface; length of the activity period of the leaf surface; productivity of photosynthesis. The first two factors are usually presented in form of a single indicator - photosynthetic potential (PP).

Long-term studies have shown that the area of leaves in a dynamic form is an indicator that can be described by a hyperbolic curve (Fig. 1).

The Figure 1 shows that the curve has one peak with a maximum in the plants flowering phase, if you take the entire spring-summer vegetation, then for winter rapeseed it is 110-115 days, including 40 days before flowering and 70 days after it. Thus, the process of leaf surface formation is more rapid than the shrinking that occurs after the end of the flowering phase. This means that rapeseed uses a rather large area of the leaf apparatus for a long time and thus realizes high production potential. Analysis of the level of influence of solar insolation on the processes of formation of plant productivity is one of the main scientific problems of crop production. Modern ideas of the process of photosynthesis come down to the fact that a quantum of photosynthetically active radiation, which is absorbed by a chlorophyll molecule, starts its activity. As a result, it gives up its electron, which migrating, spends energy on the formation of reduced forms of organic compounds. The most characteristic feature of photosynthetically active radiation should be considered precisely the ability to excite chlorophyll molecules, however, solar radiation fluxes are the only factor that cannot be artificially regulated. The main concern should only be about a more efficient use of sunlight and an increase in the efficiency that goes into photosynthesis. Light regulation of various plant functions is carried out through metabolic processes mainly through photosynthesis. This applies both to cases when, due to insufficient supply of plants with moisture, light is excessive, and when, with good supply of moisture and mineral nutrition, light is not excessive.

The main function of the leaf apparatus is the creation of organic matter, which is the goal of the whole technology of growing crops. Like the leaf surface, the aboveground biomass has an inhomogeneous growth rate and it clearly correlates with the size of the leaf surface of the plants. Each agrocoenosis is characterized by its own unique location of the photosynthetic surface in space and the corresponding use of photosynthetically active radiation by plants. Changing the structure of coenosis allows to significantly increase the level of its productivity due to varying competitive relationships. The level of photosynthesis productivity depends essentially on the leaf surface area of plants and can vary by creating the optimal optical-biological structure of agrophytocoenoses. This, in its turn, determines the basic requirement for the size of the assimilation surface,

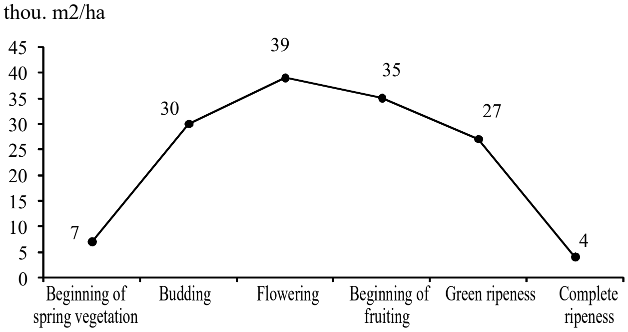

Fig. 1. Dynamics of changes in the leaf index of winter rapeseed in the control variant of the Chornii Veleten variety (Average for 2012-2016)

which should completely cover the soil surface during the growing season of plants. However, most crops at the beginning of the growing season and in its second half do not provide such coverage. Ensuring the accelerated development of the assimilating surface at the beginning of the growing season through the use of intensification factors, in particular mineral fertilizers and growth stimulants and their combined action, is one of the effective possibilities of more complete use of photosynthetically active radiation.

Winter rapeseed is a crop with a high potential for the harvest of aboveground biomass. The area of the leaf surface has the ability to vary, both due to the hydrothermal conditions of the year and to the use of elements of intensive growing technology (Table 1). The Kronos hybrid is characterized by a higher and more stable value of the net productivity of photosynthesis. With an increase in the photosynthetic potential, the productivity of the aboveground biomass also increased, but when comparing different biotypes, the postulate of a close relationship between the photosynthetic potential and the crop is not confirmed. Therefore, it can be concluded that a positive and high correlation between the photosynthetic potential and the yield of aboveground biomass occurs only within a specific biotype.

The level of growth of dry biomass is achieved by increasing the area of the photosynthetically active surface, as well as by prolonging activity duration of the leaf apparatus of plants when using intensification factors. The difference in the growth of dry biomass of the Kronos hybrid between the control variant when treating plants with pure water and the variant when early spring nutrition with nitrogen fertilizers in a dose of N_{90} in combination with double foliar treatment of plants with Helafit Combi® was 1.3 t ha^{-1}. According to the

Table 1. Photosynthetic potential and net productivity of winter rapeseed photosynthesis during the budding-flowering interphase, depending on nitrogen nutrition and growth-regulating chemicals (2012-2016)

Nitrogen nutrition (factor A)	Chemical (factor B)	Average area of leaves, thou. m^2 ha^{-1}	Length of the period, days	Photosynthetic potential, thou.m^2 ha^{-1} x days	Dry biomass increase, t ha^{-1}	NPP, g m^{-2} per day
Chornii Veleten variety (factor C)						
No nutrition	Pure water (control)	34.5	24	828	3.0	3.62
	Wuxal®	35.0	25	900	3.3	3.67
	Helafit Combi® (once)	35.8	24	859	3.3	3.85
	Helafit Combi® (twice)	37.0	25	925	3.8	4.11
N_{60}	Pure water (control)	36.2	25	905	3.6	3.98
	Wuxal®	37.8	26	983	4.0	4.07
	Helafit Combi® (once)	36.8	26	957	3.8	3.97
	Helafit Combi® (twice)	39.6	27	1069	4.3	4.02
N_{90}	Pure water (control)	38.5	25	963	3.9	4.05
	Wuxal®	40.0	26	1040	4.2	4.04
	Helafit Combi® (once)	40.0	26	1040	4.1	3.94
	Helafit Combi® (twice)	41.7	27	1126	4.5	4.00
Kronos hybrid (factor C)						
No nutrition	Pure water (control)	34.2	20	684	3.1	4.53
	Wuxal®	36.1	20	722	3.6	4.63
	Helafit Combi® (once)	35.4	20	708	3.5	4.94
	Helafit Combi® (twice)	37.1	21	779	3.8	4.88
N_{60}	Pure water (control)	38.0	21	798	3.6	4.51
	Wuxal®	39.9	22	878	3.8	4.33
	Helafit Combi® (once)	39.4	22	867	3.8	4.38
	Helafit Combi® (twice)	41.8	22	920	4.0	4.35
N_{90}	Pure water (control)	40.1	22	882	3.9	4.42
	Wuxal®	42.0	23	966	4.2	4.35
	Helafit Combi® (once)	41.4	23	952	4.1	4.31
	Helafit Combi® (twice)	43.8	23	1007	4.4	4.37

analysis of the main indicators of photosynthetic activity of winter rapeseed, both morphobiotypes early spring nutritions and treatments of plants with complex chemicals had a positive effect and a significant advantage compared to control (when treatment plants with pure water), but in terms of net photosynthesis productivity (NPP) the general regularity is broken. Therefore, it is necessary to identify ways to increase NPP against the background of an intensive nutrition system. Fertilizers and chemicals, as evidenced by the research results, increased the intensity of the leaf formation process and, accordingly, contributed to the activation of the formation and average daily growth of the leaf surface (Fig. 2).

Against the background of an increase in the rate of average daily growths in leaf surface area, it is important that after the introduction of nitrogen nutrition in a dose of N_{60} and above, this indicator slows down. During the years of research, the processes of leaf formation and growth of biomass significantly differed from the average values given, however, the difference occurred only in absolute values of indicators, and not in the specificity of the influence of nitrogen nutrition and growth-regulating chemicals, that is, the patterns noted above were observed almost identically during all years of research. Whatever the indicators related to the environment, or to the stages of plant organogenesis are considered, whatever indicators are associated with the final result, yield is still the final element in which all the intermediate results are integrated. A means of regulating the content of nutrients in the soil, their assimilation by plants at different ratios, is the nutritive regime system, which has a radical effect on the level of plants providing mineral elements. But practice shows that not only mineral fertilizers solve all issues related to the optimization of the nutritive regime. During the growing season, plants are under stress for a long time, their nutrition in such environmental conditions becomes little effective. The task of the farmer is to create appropriate conditions for the rapid removal of plants from stress. Under these conditions, it is necessary to use multi-functional chemicals that have a complex of micro-elements, notables for fungicidal action, activate microorganisms and stimulate growth processes.

According to the research results, it is necessary to pay attention first to the indicators that were due to the nutrition and the use of growth-regulating chemicals:

- The area of the assimilating surface is growing, and there is no excessive development of the leaf apparatus;
- Due to the increase in the area of the leaf surface and the duration of the base period when nourished, the indicator of photosynthetic potential significantly increases.

These facts by themselves are capable of influencing the yield of winter rapeseed, but nevertheless the complex interaction determines a stable and significant effect. The decision to choose between hybrids and varieties of winter rapeseed depends on a number of factors, such as climate and other conditions of the region where the crop is grown. The more stress factors (drought, cold, soil conditions) occur during the cultivation of rapeseed and the higher their intensity of manifestation, the more advantages hybrids have over varieties. Especially in the conditions of extremely arid zones of steppes with hard hydrothermic coefficient with low rainfall, hybrids are more resistant to these factors. Significant advantages of hybrids in comparison with linear varieties are the development of plants in the early stages in autumn, winter hardness and better ability to regrow. Seeds should be updated annually due to signs of hybridity. Re-cultivation of hybrids is impractical due to the separation of crossing lines. The advantage of linear varieties is their greater variety and, on average, somewhat higher oil content of grain. However, the varieties are not tolerant to sowing dates and do not satisfactorily respond to a shift in sowing dates towards later ones (from mid to late September). The research results showed that in terms of productivity, the Kronos hybrid prevails over the Chornii Veleten variety by 0.49 t ha^{-1}, or 17% (Table 2).

The productivity of hybrids was 12-18% higher than varieties. But, if consider the specificity of the reaction of the variety and the hybrid to the nutrition, the Chornii Veleten variety provided an average yield increase with nitrogen in a dose of N_{60} of 0.26 t ha^{-1} and in a dose of N_{90} of 0.50 t ha^{-1}. As for the Kronos hybrid, the increase in yield from nitrogen nutrition was 0.44 t ha^{-1} in a dose of N_{60}, 0.72 t ha^{-1} in a dose of N_{90}, which indicates the feasibility of hybrids nutrition, which per kg of the active substance of nitrogen provide a higher increase (Fig. 3).

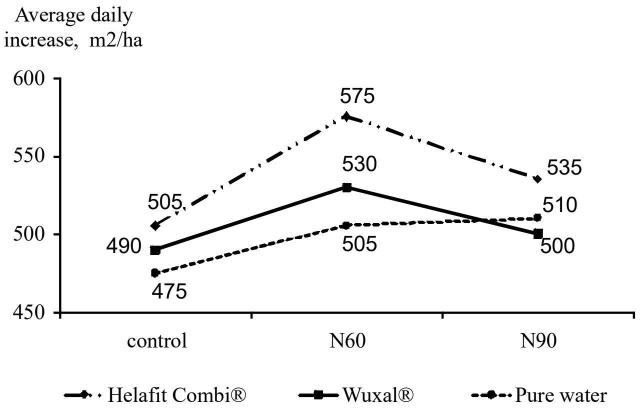

Fig. 2. Average daily increase in leaf area in the phase of budding-flowering (2012-2016)

Table 2. Productivity (t ha^{-1}) of winter rapeseed depending on nutrition and growth-regulating chemicals, (average for 2012-2016)

Nitrogen nutrition (factor A)	Chemical (factor B)	Morphobiotype (factor C)					
		Chornii Veleten			Kronos		
		Dry biomass	Seed	Per cent of seeds to biomass	Dry biomass	Seed	Per cent of seeds to biomass
No nutrition	Pure water (control)	10.2	2.10	20.6	10.0	2.40	22.7
	Wuxal®	10.9	2.29	21.0	10.7	2.61	24.4
	Helafit Combi® (once)	10.3	2.26	21.9	10.5	2.58	24.6
	Helafit Combi® (twice)	11.3	2.39	21.1	11.1	2.75	24.8
N_{60}	Pure water (control)	11.2	2.36	21.1	11.3	2.71	24.0
	Wuxal®	12.1	2.52	20.8	11.9	2.91	24.5
	Helafit Combi® (once)	11.9	2.48	20.8	11.7	2.90	24.8
	Helafit Combi® (twice)	12.5	2.61	20.9	12.2	3.04	24.9
N_{90}	Pure water (control)	12.5	2.60	20.8	12.5	2.99	23.9
	Wuxal®	13.4	2.79	20.8	13.1	3.21	24.5
	Helafit Combi® (once)	13.0	2.77	21.3	12.9	3.16	26.3
	Helafit Combi® (twice)	13.6	2.89	21.3	13.5	3.38	25.0

$LSD_{0.05,}$ (for dry biomass), t ha^{-1}: ABC – 0.08; $LSD_{05,}$ (for seed), t ha^{-1}: ABC – 0.06

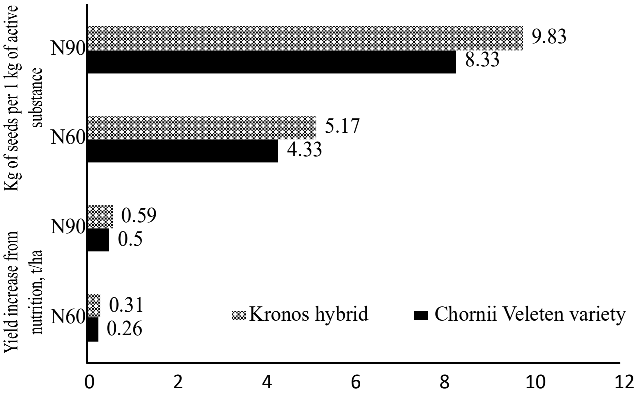

Fig. 3. The yield increase from nitrogen nutrition, depending on the biotype of winter rapeseed, (average for 2012-2016)

From the present study, can draw two conclusions: firstly, the nitrogen dose of 90 kg ha^{-1} of the active substance is more effective both in terms of increase and of return of the yield per unit of active substance; secondly, the Kronos hybrid uses nitrogen from nutrition better for crop formation. The advantage of the hybrid in return against the background of N_{60} is 15.7%, and against the background of $N_{90}$is 18%. No less clearly observed yield increase from the use of these two chemicals. The results of field studies indicate the same regularity as in the case with nutrition with nitrogen fertilizers, the hybrid is more effective in terms of response to chemicals, but if in the first case the advantage of the Kronos hybrid was due to the high level of intensity, then in the second, despite the higher level of vulnerability to stress compared with the variety, this negative is minimized due to the anti-stress effect of the chemicals and thus causes a deep realization of the potential of the hybrid.

CONCLUSIONS

From the above data, it is absolutely necessary to draw two conclusions: firstly, a nitrogen dose of 90 kg ha^{-1} of active substance is more effective both in terms of increase and of return of the yield per unit of active substance; secondly, the Kronos hybrid uses nitrogen from nutrition better for crop formation. The advantage of the hybrid in return against the background of N_{60} is 16.1%, and against the background of N_{90} is 18%. The maximum seed yield with a more favourable ratio of generative and vegetative components is achieved by nutrition winter rapeseed with nitrogen fertilizers in a dose of N_{90} in combination with double foliar treatment of plants with Helafit Combi® and, according to the research, equals to 2.89 t ha^{-1} of conditioned seeds for Chornii Veleten variety and 3.38 t $ha^{-1}$of conditioned seeds for Kronos hybrid.

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