SECTION 1. AGRONOMY

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1.1 Evaluation of elements efficiency of winter rye cultivation technology in the conditions of Zhytomyr Polissia

In the Polissia region, on acidic, low-fertile, light gray forest soils, it is advisable to allocate the main areas to winter rye, which provides a higher yield of high-quality grain compared to winter wheat, whose share should not exceed 70 %. It is the best of all cereals, adapted to the growing conditions in Polissia.

Assessing the overall state of grain farming development, it should be noted that its dynamics is unstable. Undoubtedly, the difference in gross grain harvest in certain years is due to both unfavorable climatic conditions and low technological support for grain crops. Therefore, increasing their yields requires significant costs and efforts from scientific institutions and producers, including the use of modern machinery, fertilizers, plant protection products, reduction of the costly mechanism of their cultivation, and advanced resource-saving technologies.

At present, the reduction of sown areas under rye, especially in the current conditions, is not justified, as it is one of the reserves for improving the structure of sown areas among cereals and increasing gross grain harvest through the introduction of new varieties and hybrids. Nature has endowed winter rye with a number of distinctive qualities: it has high consumer value and versatility of use, and can generously recoup costs even in unfavorable soil and climatic conditions. Winter rye is the second most important crop in our country after wheat. Winter rye holds one of the leading positions in the grain balance of Ukraine. Rye is better adapted to soils with low natural fertility than other crops. The biological characteristics of this crop are such that it uses soil moisture better than spring cereals in autumn and early spring, and is less affected by summer drought. Therefore, rye can serve as a crop in many regions of Ukraine.

However, the spread of mycoses in winter rye crops has a significant impact on grain yield and quality. Brown rust can cause a significant reduction in grain yield and quality, but the presence of infection does not always lead to yield loss or an economic response to fungicide use.

The phytosanitary situation in the agrocenosis is formed depending on many factors: meteorological conditions of the growing season, level of agricultural technology, crop rotation, sowing qualities of seeds, genetic characteristics of cultivated varieties, etc. Thus, the increased use of minimal, zero-till technologies, with less varietal diversity, contributed to the accumulation of an infectious background, increased the prevalence and harmfulness of particularly dangerous diseases, a complex of aerogenic infections It is known that at high intensity of plant leaf damage, pathogens can significantly reduce their assimilation capacity and, accordingly, crop yields. Thus, epiphytic development of infections can lead to liquefaction and complete death of crops. All of this necessitates the study and analysis of the main aspects of the use of modern plant protection products. Timely diagnosis of diseases and analysis of their dynamics help to increase the effectiveness of protective measures.

Therefore, the *purpose* of the research was to study the effects of plant growth regulators and fungicides on winter rye to select the most effective preparations that improve the phytosanitary condition of crops and increase crop productivity.

The experiment was conducted using both laboratory and field methods. The technology of winter rye cultivation was generally accepted for the Polissya zone, only the element of the protection system differed. Accounting of brown rust damage was carried out in accordance with accepted methods. The economic and mathematical method was used to calculate economic efficiency. Statistical processing was carried out using computer programs.

Rye is a versatile crop. However, its main use is for food. Due to its balanced nutritional content, rye bread has been providing adequate nutrition for the population of vast areas of the country for several centuries. Rye bread made from wholemeal flour with sourdough starter cultures was not only a food product, but also a permanent powerful preventive measure against obesity, atherosclerosis, coronary artery disease, nervous and even cancer. Natural rye bread protected the offspring, and thus the health of the entire nation [1, 2].

Most rye grain is used for fodder purposes. The presence of anti-nutrients in rye grain limits its use in livestock and poultry feeding, but various grain processing methods (extrusion, fermentation, flattening, canning, etc.) allow up to 70 % of the total amount of concentrates to be used in animal feeding. Scientific studies have shown the positive value of winter rye in feeding, but also in reproduction of cattle herds [3].

In the spring, rye produces green mass earlier than other crops, which can be used for feeding all types of livestock and poultry, for laying haylage and early silage, and for making highly nutritious grass flour and pellets. Mixed crops of winter rye with winter vetch are promising for producing high-quality bulky fodder and grain fodder [4].

In addition to food and feed, winter rye grain is valuable as a technical raw material for starch and alcohol production.

High adaptability, stable grain yields, and agrotechnical importance as a good precursor, combined with its traditional use in rye bread, fodder production, and production of starch, alcohol, and other products, make rye one of the most important crops. Among cereals, it has the lowest requirements for soil fertility, fertilizers, herbicides, and pesticides, which means it produces environmentally friendly and cheap grain [5].

However, we can observe that globally and in Ukraine, there is a decline in winter rye acreage. The decrease in the area in the northern regions, where rye is the most adapted crop to the difficult farming conditions, is particularly alarming. Due to its high winter hardiness and drought tolerance, low requirements for cultivation intensity, rye is rightfully considered a low economic risk crop that grows successfully on low-fertility sod-podzolic acidic soils, the share of which is more than 70% in the European northeastern part of the country alone [4].

Scientific institutions have created highly productive varieties of winter rye for specific growing conditions, developed zonal technologies for their cultivation, and accumulated many years of experience in successfully growing this crop [6].

A promising resource-saving technology is recommended for rye grain producing regions, especially for northern agriculture, and is based on the following principles: use of adaptive varieties; placement according to recommended predecessors; scientifically based soil cultivation system; rational use of mineral fertilizers; timely sowing and plant care; integrated plant protection system against pests, diseases and weeds; harvesting at the optimum time, proper grain processing and storage.

The feasibility of growing winter rye using resource-saving technologies is determined by the possibility of obtaining a grain yield in production conditions of at least 3.0–4.4 t/ha [7].

Maintaining consistently high grain yields is largely facilitated by the resistance of varieties to diseases. Breeding of short-stemmed rye has significantly exacerbated this problem and led to a sharp increase in harmful diseases. In this regard, the development of winter rye varieties resistant to dangerous pathogens is an important area of breeding work [8].

The phytopathogen usually overwinters on rye in urediniomycetes. At the same time, urediniospores remain viable. Thus, the fungus can develop in an incomplete cycle. In this case, only the urediniostage develops. Other stages are not essential in the development of the fungus. With the massive formation of urediniospores, neither teliospores nor eciospores play a significant role in the development cycle of the phytopathogen, since the main source of spring renewal of brown rust is winter rye crops infected with urediniospores and urediniomycelium in the fall [9].

Fig. 1.1. Affected leaves of winter rye with brown leaf rust, 2023

The pathogen multiplies in a wide temperature range. For the formation of epiphytosis, the phytopathogen primarily requires heat. Days with active solar radiation at a temperature of +20°C–+26°C in combination with warm nights (optimally +15°C), precipitation or dew in the evening (moistening of plants for at least four hours in a row) contribute to the development of the infection [10].

A dangerous surge in reproduction usually occurs in the fall after heading. Winter crops can be infected in the fall with mycelium and spores. In spring, urediniospores can be transported over long distances by air currents [6]. A large number of infected plants with successfully overwintered urediniomycelium at warm temperatures in spring and autumn can cause active development of the disease, especially in rye varieties that are not resistant to the phytopathogen.

In addition, early sowing, unreasonably high doses of nitrogen fertilizers, the presence of massive shoots of carrion, the presence of intermediate host plants, and the presence of brown leaf rust epiphytosis last year contribute to the development of the disease [3].

Symptoms of the lesion External signs appear on the leaves and leaf sheaths in the form of subepidermal, rusty-brown uredosorus. Later, the tissues darken due to the formation of teleutosorus in them. In contrast to stem rust, the teletosoruses of brown rust are closed. Usually the sori are scattered on the upper side of the leaf and very rarely on the lower side. In resistant varieties, chlorotic spotting appears near the sorus, while in immune varieties the spots remain sterile. The disease develops throughout the growing season, but most often in the period from ear emergence to maturation. In case of severe damage, a burn appears on the crops. Damage to the top leaf has a particularly negative effect on the yield. Plants remain stunted and form smaller ears. The grain is small, light, and powdery at the break [5].

Factors contributing to the development of the disease [11]***:***

- high humidity and temperature of 18–22 ^{0}C;
- thickened crops;
- high doses of nitrogen fertilizers.

Agrotechnical measures and chemical plant protection methods are often ineffective, able to only slightly reduce the harmfulness of the disease, but not prevent its development, while causing environmental damage. The most effective method of protection is the creation of resistant varieties using breeding methods. Targeted differential breeding is required to develop varieties that retain resistance for a long time, taking into account the specifics of the sources of resistance genes and the possibility of their transfer to selected varieties.

As for horizontal resistance, it should be noted that it is present in different populations of varieties and is known as field resistance. When epiphytoties develop, not all varieties are equally affected by pathogens. In rye, it is not yet known how reliable race-specific resistance is due to the possibility of overcoming it when new mutant races of pathogens emerge.

The most effective protection measures against the development of brown leaf rust include [3]***:***

- not to grow rye in monoculture;
- sow at the optimal time;
- apply complete nitrogen-phosphorus-potassium mineral fertilizers;
- grow resistant varieties;
- at the degree of damage of 10–20 % of the leaf surface, carry out chemical treatment of crops with Strike Forte, Sintron, Fargo, Flint, Protazox, and Crestrazh.

Fungal diseases in winter rye crops are one of the factors of significant crop yield shortfall. The dominant and most harmful is brown leaf rust of winter rye – *Puccinia dispersa*.

Field studies to determine the percentage of powdery mildew spread and development were conducted in the conditions of the training and research field during the growing season of the crop in 2021–2023.

The farm where the research was conducted is dominated by light gray forest soils, and it belongs to the northern zone of the Zhytomyr region and is characterized by good favorable conditions for farming and growing crops. One of the crops we are studying is winter rye.

The humus horizon of the soil under study is 14–18 cm deep.

The granulometric composition of the soil is light loamy and structureless, and its density is in the range of 1.2–1.4 g/cm3.

The indicators of the arable layer: humus content is 1.95–2.63 %, alkaline hydrolyzed nitrogen is 45–60 mg/kg, mobile phosphorus by Kirsanov is 80–120 mg/kg of soil, exchangeable potassium by Kirsanov is 95–135 mg/kg of soil, and PH is within 5.5–6.1.

The weather conditions were favorable for research and cultivation of winter rye in Polissia of Ukraine.

The climate of Zhytomyr region is temperate continental. The continentality increases from northwest to southeast and is manifested in fluctuations in temperature and relative humidity, uneven distribution of precipitation throughout the year and by years, and pronounced dry periods. The average air temperature in the coldest month (January) varies from –10.9 °C in the north to –8.2 °C in the south, and in the warmest month (July) from 19.6 to 21.8 °C, respectively.

The growing season generally lasts 180–200 days. The sum of active temperatures ranges from 2300–2440 °C in the northwest to 2800–2900 °C in the southeast. The average long-term precipitation per year is 554 mm.

Most precipitation falls as rain and one third as snow. The period with an average daily air temperature of +5.0 °C begins on April 11–15 and ends 184–190 days later, on October 17–20. The period with an average daily temperature of +10 °C begins on April 25–28 and ends on September 26–28 (150–160 days). The sum of average daily temperatures above 5 °C is 2700–3100 °C, and above +10.0 °C is 2400 2600 °C. The frost-free period lasts from April 1–4 to October 1–4 (150–158 days).

In terms of moisture availability, the northern districts of the region belong to the zone of unstable moisture. There is an uneven precipitation pattern by month and season. Droughts and dry winds are common. As a result, plants suffer from a lack of moisture and are therefore vulnerable to early autumn or late spring frosts, and in severe winters, under the influence of unfavorable conditions, the crop will be significantly thinned out in spring, and some areas may even die completely.

Rye overwintered in December under satisfactory conditions. During the thaw, winter crops were in a state of shallow dormancy. There was an increased consumption of nutrients for respiration, which reduced their winter hardiness. The minimum soil temperature at the depth of the tillering node was 1-6 °C below zero.

The first ten days of May were characterized by cold weather. The average daily temperature was 3–4°C and 9–10°C below normal. In the third ten-day period of May, the weather was dry and very hot. The average daily temperature was 27–29°C, which is 10–12°C above normal. Overall, May was 3–4°C warmer than usual in terms of temperature. Hot, dry weather and a lack of moisture in the topsoil complicated the growth and development of winter crops. During the day, the plants lost turgor. The average regional air temperature in June was 19–21°C, which is 1°C above normal. The average regional precipitation amounted to 67 mm, or 111 % of the June norm. Grain ripening conditions deteriorated due to high humidity. In July, grain ripening continued in winter crops. The average precipitation in August was 25 mm or 45 % of the monthly norm. On August 27–28, the productive moisture reserves in the tilth layer of the soils in the field intended for sowing winter crops were mostly insufficient, 11–14 mm.

Weather conditions, due to a decrease in plant density in crops, plant productivity, were one of the factors determining the yield and grain quality of the studied winter rye varieties over the years of research (in control experiments).

Observations have shown that meteorological conditions were favorable for the development of powdery mildew of winter rye, and its development was recorded.

To take into account the phytosanitary condition of winter rye crops, observations were made at the experimental site in the farm where the crop is affected by diseases characteristic of this zone. Observations of the disease development were carried out from February 25 (developmental stage EU 15) to July 18 (EU 87), according to the scale of phenological stages of BBSN.

At each survey, samples were taken from 100 plants – 10 from 10 locations along the diagonal of the field. The analysis of each sample was carried out visually using an eye scale.

Scheme of the research

Determination of the effectiveness of fungicides and plant growth regulator in winter rye phytocoenoses against the development of brown leaf rust:

1. Control (water treatment).

2. Abacus Plus, CE, 0.8 l/ha + Ecostim-1, RK, 1.5 l/ha

3. Ajax, CS, 0.5 l/ha + Ecostim-1, RK, 1.5 l/ha

4. Greenford KD 500, FF 0.4 l/ha + Ecostim-1, RK, 1.5 l/ha

5. Impact 500, FF, 0.2 l/ha + Ecostim-1, PK, 1.5 l/ha

Spraying of phytocoenoses with fungicides and a plant growth regulator of winter rye was carried out at the 30th stage of crop development. The area of the recording plot was 10 m^2, replication was four times, and the variants were randomized.

Monitoring the spread and development of brown rust in winter rye phytocoenoses.

Brown leaf rust (*Puccinia dispersa*) – appears on the sheaths and leaves of rye in the form of brown pustules, which later turn into black, glossy bodies. The location of the lesions is random. The infection is widespread in the Polissya region (Fig. 1.2).

Fig. 1.2. Affected leaves of Puccinia dispersa, 2023 (*original photo*)

The appearance of visual symptoms of the disease is recorded on young seedlings and adult plants. The phytopathogen infects rye seedlings in the fall and, starting in spring, develops throughout the growing season. Usually, on the upper, and rarely on the lower side of the leaves and sheaths, there are many randomly scattered oblong or rounded uredinia, rusty brown or brick red in color, which look like powdery pads. Over time, clearly visible black pads form on the underside of the affected organs under the epidermis. Uredinia are usually surrounded by "green islands", a kind of light halo. The reason for their formation is the stimulation of the flow of nutrients from healthy tissue by the intercellular mycelium (urediniomycelium) of the phytopathogen. At the same time, the tissues surrounding these "islands" age rapidly.

Urediniospores are unicellular, elliptical or spherical, slightly brownish, with a spiny shell. Size 20.0-28.0x17.0-22.0 microns. There are 8-10 germination pores evenly distributed on the surface.

Teliospores are bicellular, club-shaped or oblong. The color is light brown, the apex is thickened and darker colored. The leg of the teliospore is short and almost colorless.

The phytopathogen has many physiological races of different geographical distribution and is specifically confined to host plant genotypes.

Brown leaf rust of rye is a dangerous plant disease that periodically occurs as an epiphytotic disease. It contributes to a significant reduction in yield due to leaf burns and a decrease in their assimilation surface. Yield losses occur due to a decrease in the weight of thousands of grains and a decrease in protein content.

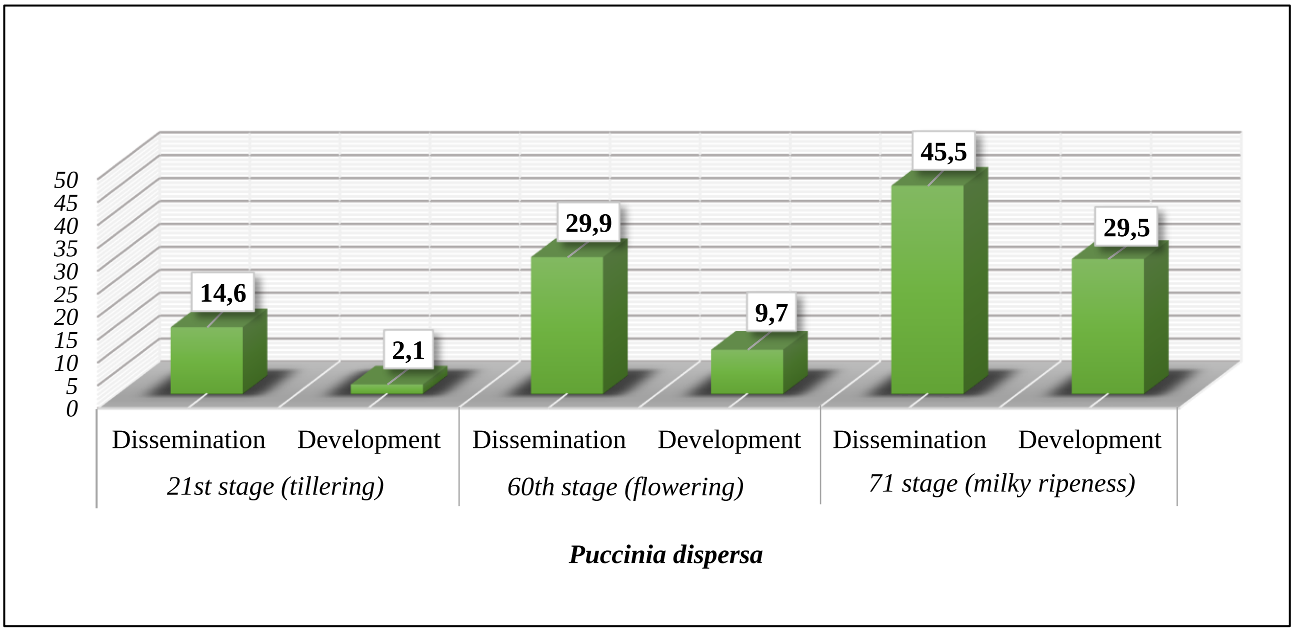

Figure 1.3. Dynamics of brown rust development in winter rye at different stages of organogenesis (variety Synthetic 38, 2021-2023)

The analysis of the results of the research showed that the development of brown leaf rust increased during the growing season of winter rye. The first symptoms of the disease appeared at the 21st stage of spring tillering and amounted to 2.1 %. The disease reached its maximum value at the 71st stage of milky-wax ripeness of winter rye at 29.5 %.

Mycoses play an important role in reducing the yield of winter rye. They affect the aboveground parts of the plant, causing tissue death. The main pathogen that causes significant yield losses in all countries where crops are grown, including Ukraine, is the fungus Puccinia dispersans, the causative agent of brown leaf rust.

During the study period of 2021–2023, yield losses caused by the pathogen *Puccinia dispersifolia* were detected (Fig. 1.4).

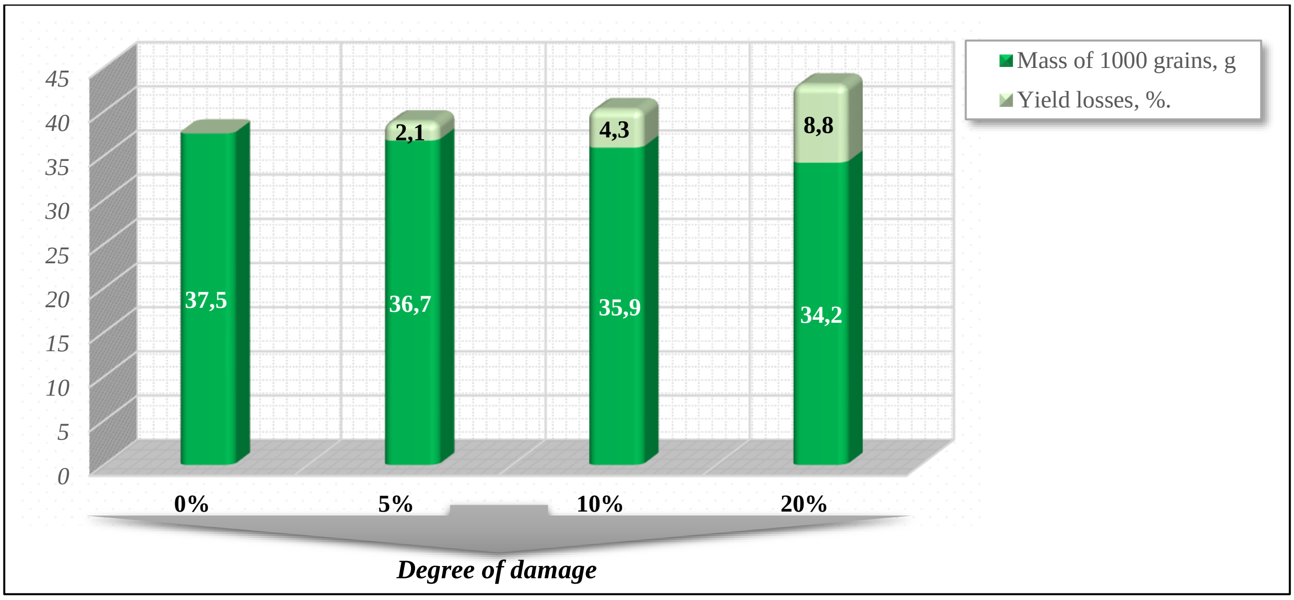

Fig. 1.4. Harmfulness of brown leaf rust of winter rye
(variety Synthetic 38, 2021-2023)

The highest yield losses were 8.8% when the rust development was more than 20%, which was reflected in the weight of 1000 grains, which decreased from 37.5 to 34.2 g. The minimum losses (2.1%) were recorded when the rust development was 5%, and the largest losses were recorded when the rust development was 20% and amounted to 8.8%.

Evaluation of measures to control and limit the spread and development of brown leaf rust.

Fungicides are used to protect plants from diseases. They affect the metabolic processes of fungal cells and inhibit enzymes in pathogen cells and are sources of infection in the development of various diseases. Treating plants during the growing season with a fungicide will increase your benefits by protecting the health of your winter rye and future crops.

The concept of integrated plant protection is in line with the principles of ecologization and environmental protection, which involves the integrated use of modern agricultural technology, resistant varieties, and rational use of pesticides. The need to use pesticides is driven by growing losses from pests and weeds, deteriorating quality of crop products and lack of real alternative methods, shortage of resistant varieties, and high cost-effectiveness of pesticides.

It has been experimentally proven that the simultaneous application of growth regulators and fungicides with the correct selection of the composition of tank mixtures increases their effectiveness by 1.5–2 times or more. In Fig. 1.5 shows the results of studies on the effectiveness of fungicides and a plant toast regulator against brown leaf rust.

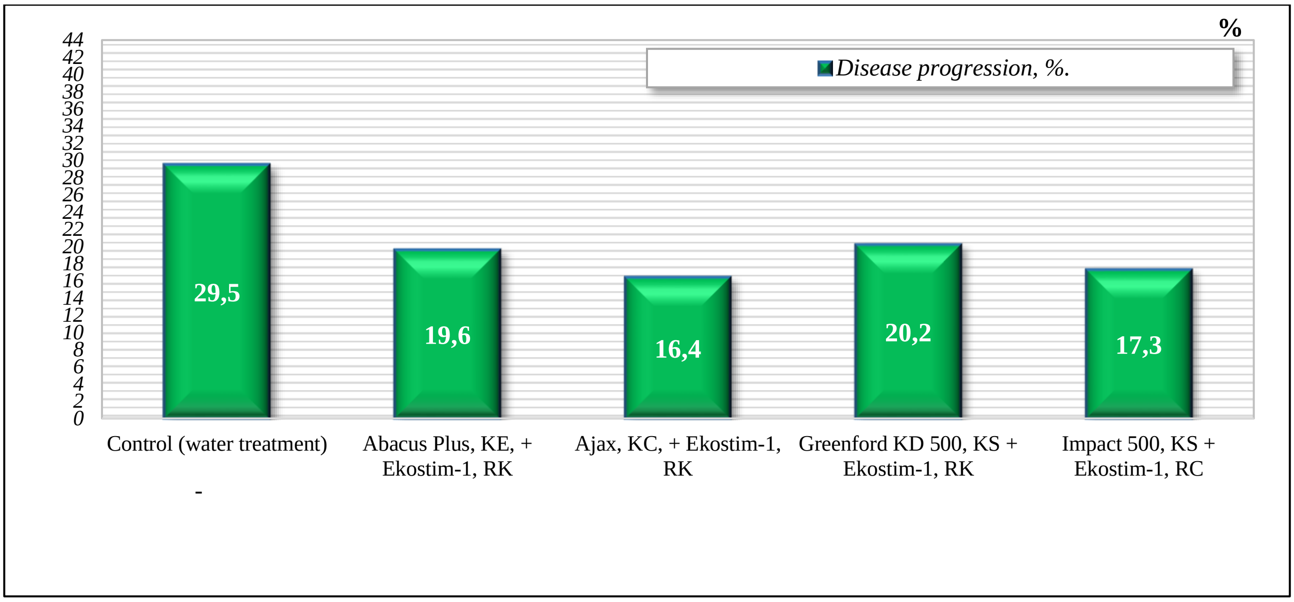

Fig. 1.5. The effect of complex protection of winter rye on the development of brown leaf rust (Synthetic 38, 2021-2023)

The combined use of the plant growth regulator EKOSTIM-1, RK and fungicides had a positive effect on the dynamics of brown rust development in winter rye.

The lowest development of brown rust was recorded in the variant where the crops were sprayed with a mixture of Ajax, CS, 0.5 l/ha and EKOSTIM-1, RK, 1.5 l/ha, which was 15.4%, which is 13.1% lower than in the control.

The purpose of the study was to investigate the effects of plant growth regulators and fungicides on winter rye to select the most effective products that improve the phytosanitary condition of crops and increase crop productivity.

The intensive development of brown rust allowed us to obtain objective data on the technical effectiveness of the fungicides and plant growth regulator used. Decisions on the need for protective spraying against brown rust were based on relevant criteria. The applied fungicides did not have a negative impact on the sowing quality of seeds. In particular, the germination energy and seed germination did not differ significantly between the treated and control variants.

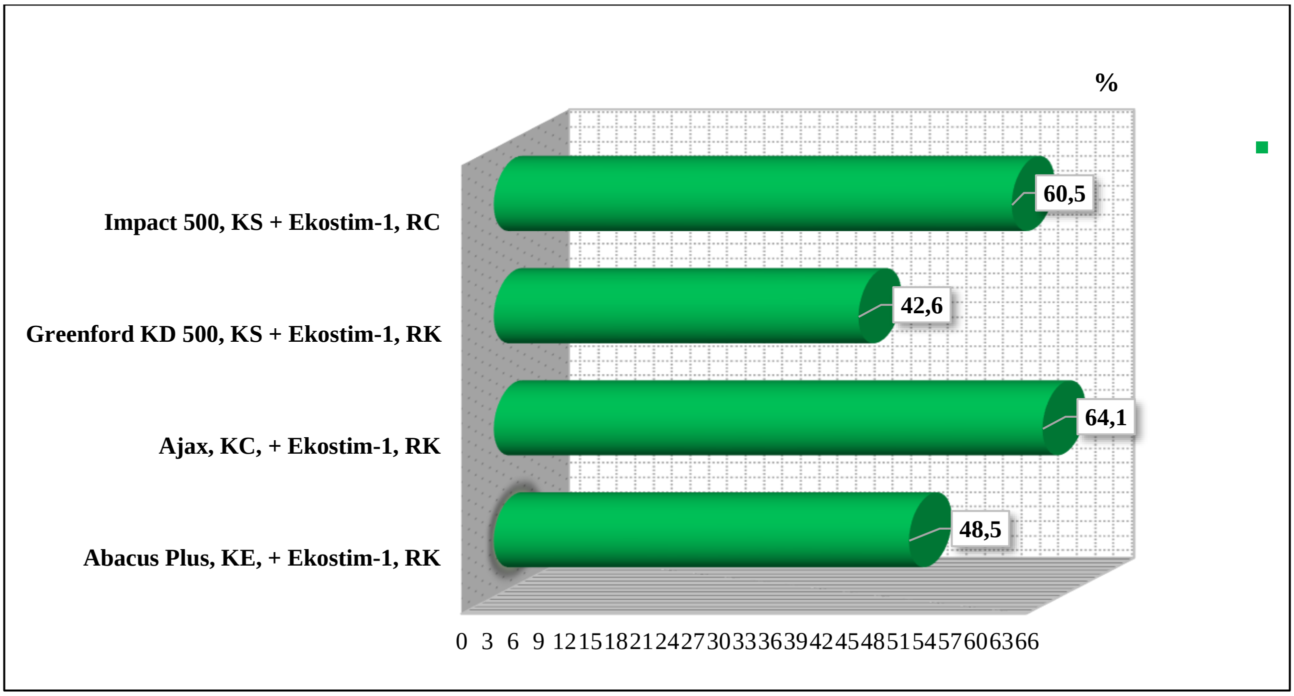

Fig. 1.6. Technical effectiveness of fungicides and plant growth regulator against the development of brown leaf rust of winter rye (variety Synthetic 38, 2021-2023)

The results of the research in Fig. 1.6 showed that the combined use of growth regulator and fungicides in winter rye phytocoenoses contributed to the enhanced process of stem formation, the ear was formed longer in size, the weight of seeds per 1 ear and their grain size increased. It should be noted that this trend was observed in all variants.

Technical efficiency in the studied variants varied from 42.6 to 64.1%. The highest rates were recorded in the variant of joint application of Ajax, CS, 0.5 l/ha and Ekostim-1, RK, 1.5 l/ha, which amounted to 64.1%.

Brown leaf rust can cause a significant reduction in yield and grain quality, but the presence of infection does not always lead to yield loss or an economic response to fungicide use.

Varietal susceptibility, seasonal weather conditions, yield potential and timing of infection all influence the likelihood of yield impact. Infection early in the season can significantly reduce yields of susceptible varieties (up to 25%) by reducing photosynthetic leaf area and nutrient availability to plants, but more importantly by affecting yield potential by stimulating excessive non-grain stem formation. Severe infection can also cause crop lodging due to weakened stems. The earlier the infection occurs, the longer it persists and the higher up the plant it spreads, the greater the potential yield losses.

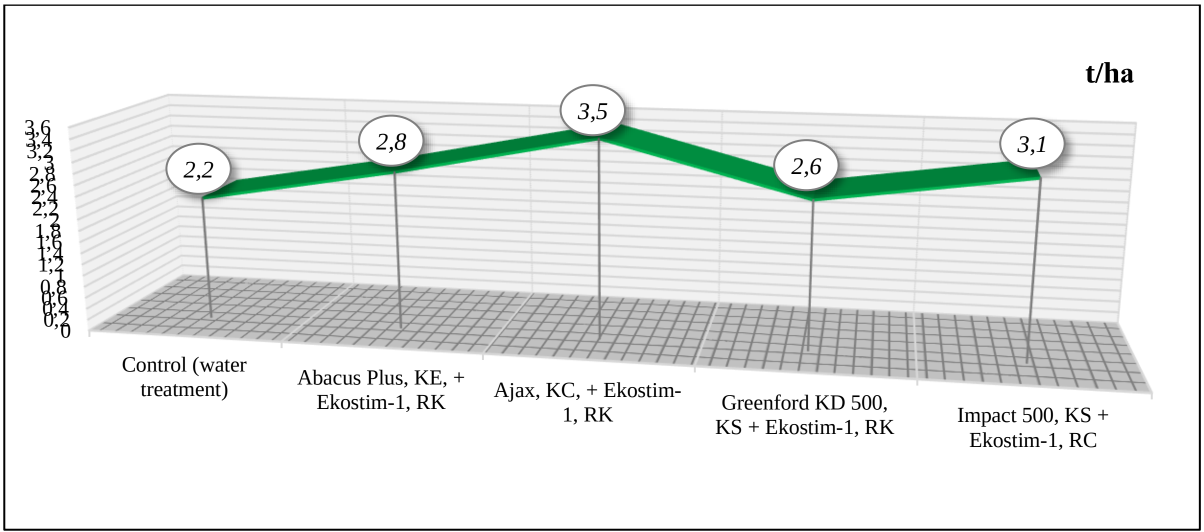

Fig. 1.7. Yield of winter rye under the complex application of fungicides and plant growth regulator against the development of brown leaf rust (Synthetic 38 variety, 2022–2023)

The level of yield obtained depending on the proposed measures of protection against brown leaf rust in winter rye phytocoenoses is shown in Fig. 1.8.

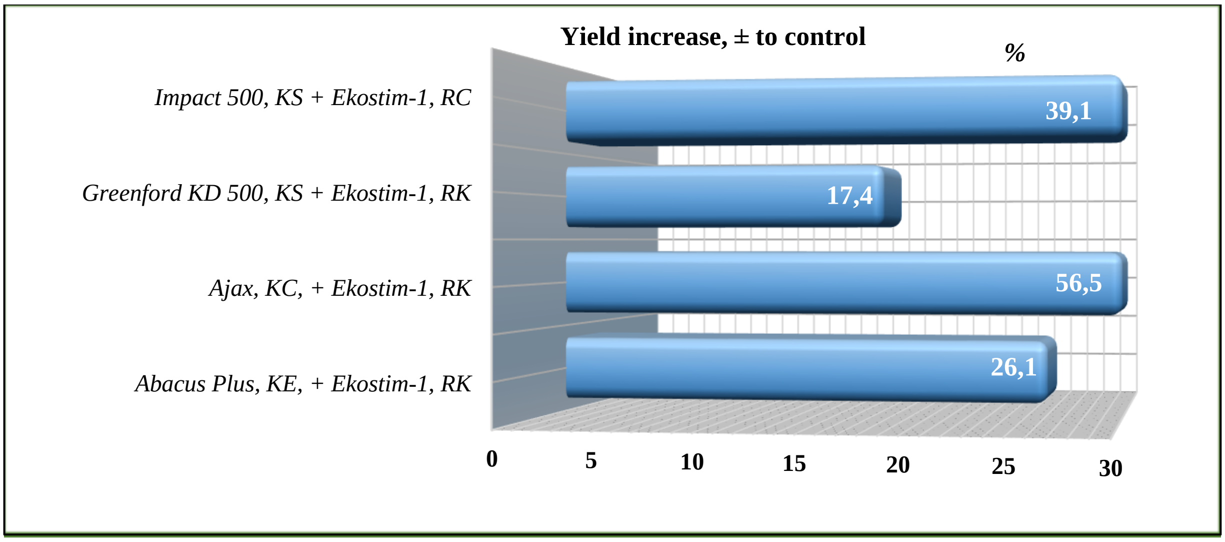

Fig. 1.8. Increase in yield due to the complex application of fungicides and plant growth regulators against the development of brown leaf rust (Synthetyk 38 variety, 2022–2023)

The increase in the yield of winter rye grain with the complex application of fungicides and plant growth regulator provided an increase in the yield at the level of 0.4 to 1.3 t/ha.

The maximum yield of winter rye was provided by the mixture of Ajax, KS with a consumption rate of 0.5 l/ha and Ecostim-1, RK, 1.5 l/ha, which amounted to 3.6 t/ha, which provided an increase of +1.3 t /ha, or 56.5%.

Economic effectiveness of winter rye protection systems. The modern practice of the chemical method of plant protection is based on ecologically, economically and toxicologically justified application of pesticides. Some economic aspects of the use of fungicides on winter rye crops are considered in the paper. It is shown that the cost of treatment with fungicides pays off in terms of yield increases. How economically expedient are repeated treatments of winter rye crops with fungicides. The effectiveness of the combined use of fungicides and plant growth regulators is evaluated depending on the use of various other intensification factors (Table 1). Calculations were carried out according to generally accepted methods, taking into account the normative price indicators of 2023.

Table 1. **Economic efficiency of growing winter rye depending on the complex application of fungicides and a plant growth regulator against the development of brown leaf rust (Synthetyk 38 variety, 2022–2023)**

Indicator Grade	Synthetic 38	
	control (without protection)	complex spraying of crops
Productivity, t/ha	2,2	3,5
Labor costs, man-hours/hour	0,52	0,52
Material and monetary costs, hryvnias/ha	4928,69	6007,8
Production cost t, hryvnias	2142,91	1668,83
Net profit	1971,31	4785,8
Production profitability level, %	38,6	74,8

The analysis of economic efficiency showed that the profitability of the complex application of the plant growth regulator Ekostim-1, RK and the fungicide Ajax, KS at a reduced rate of use was 74.8%, and the net profit was UAH 4,785.8/ha.

Cultivation technologies are a crucial link of the production process, their importance will increase, and the future lies behind them [7].

Cultivation of winter grain crops using intensive technology is an effective measure and economically profitable, when the increase of grain relative to the yield of the reference variant is not lower than 10 t/ha. This can be achieved by the correct application of the main factors of intensification of grain production, as well as fertilizers, mostly nitrogen, and an integrated system of protection against pests, diseases, lodging and weeds [4].

The main goal of intensive technologies is the formation of the maximum yield of winter crops, which is possible if a complex of agroforestry practices is developed, which include providing plants with a sufficient amount of all nutrients during the growing season.

The intensive technology of growing winter rye involves a number of specified agrotechnical measures. It includes placement of winter rye according to the corresponding predecessors; introduction of intensive varieties; soil cultivation, which ensures the creation of favorable water and nutrient regimes, and improvement of the physical properties of the soil; optimization of mineral, especially nitrogen, nutrition during the growing season of plants; fractional application of nitrogen fertilizers according to the main stages of organogenesis, taking into account the results of soil and plant diagnostics; integrated protection of plants from weeds, pests, diseases, lodging; timely and high-quality performance of all agrotechnical measures for sowing and harvesting, use of a technical complex of machines and tools [9].

A number of authors note the effectiveness of mineral fertilization of winter rye and recommend the application rate of $N_{120}P_{90}K_{90}$ specifically on sod-podzolic soils. Nitrogen fertilizers have the highest influence on the protein content of grain. When N_{150} was added, the protein content rose to 13.6% compared to 11.7%.

It has been established that among grain crops in the Polissia of Ukraine, the highest costs of total energy per 1 ha are noted for the cultivation of spring wheat and the lowest – for wheat and rye. The variety of winter wheat and rye productivity results in production indicate unused rye reserves. Breeding of highly productive short-stemmed varieties of winter rye and their introduction will really allow to change the ratio of areas of winter wheat and rye in the structure of winter crops, bringing the share of the latter to 1/3.

Winter rye successfully competes with winter wheat, this is demonstrated by the results of many scientific studies, the real prospect of rye receiving more than 1 million tons of grain annually.

We studied a three-field crop rotation with the following fertilizer options:

Variants of fertilization systems

1. Biological control
2. Organo-mineral system (37.5 t/ha of manure + $N_{12.5}P_{10}K_{17.5}$)
3. Organic system (siderates – 12 t/ha)
4. Mineral system – $N_{50}P_{40}K_{70}$

Winter rye was grown according to generally accepted agricultural techniques for the northern zone of Polissia. Winter rye is grown on different soils, but under the condition that the thermal properties of the region, moisture, soil aeration, which are important elements, will be at the very end during the period of formation of this crop [1].

The farm envisaged a research scheme for the introduction (by spreading method) of the following amount of NPK under winter rye, namely:

1. Nitrogen – 60 kg per ha (ammonium nitrate and urea);
2. Phosphorus – 40 kg per ha (simple superphosphate);
3. Potassium – 70 kg per ha (potassium chloride and potassium salt).

Agrotechnological efficiency. Considering the dependence of winter rye yield on the fertilization system on light-gray forest soil, the following results were obtained.

In the variant without fertilizers (Biological control), the yield of rye grain was low and amounted to only 2.33 t/ha.

It can be said that the highest level of productivity was under the mineral fertilizer system and is 3.38 t/ha, which is 1.05 t/ha more than the control.

In second place is the option with the organo-mineral system, where the yield was 3.2 t/ha, which is 0.9 t/ha more than the control, and 0.14 t/ha lower than the maximum yield obtained with the mineral system. In the variant where only the organic fertilizer system was used, an insignificant increase in the yield of rye grain was observed in comparison with the control.

Table 2. **Yield of winter rye depending on fertilization systems, t/ha**

Fertilizer system	Урожайність, т/га			Average, t/ha	+/- to control, t/ha
	2021	2022	2023		
Biological control	1,81	3,13	2,06	2,33	-
Organo-mineral system	2,77	3,75	3,20	3,24	0,91
Organic system	2,31	3,57	2,26	2,71	0,38
Mineral system	2,59	3,78	3,77	3,38	1,05

Thus, the yield was 2.71 t/ha, which is 0.38 t/ha more than the control. Taking into account the results of the yield of winter rye for 2021, we can conclude that the most effective fertilization system was the mineral system, and the lowest level of yield was shown by the organic fertilization system.

Environmental efficiency. Let us consider in comparison the following flour milling properties, which were obtained during cultivation on different fertilization systems, namely (nature g/l, weight of 1000 grains g, vitreousness). The best nature of 718 g/l rock mineral system with a small weight of 1000 grains compared to other results. The highest vitreousness was for the mineral system and for the organo-mineral system, the last of which showed the highest mass of 1000 grains, but did not exceed the mass of the control. Cultivation of winter rye under an organic system (siderates – 12 t/ha) showed rather lower flour milling properties compared to other options.

Table 3. **Flour milling properties of winter rye grain (2021–2023)**

Fertilizer system	Indexes		
	nature g/l	weight of 1000 grains, g	vitreous, %
Biological control	693	42,8	29
Organo-mineral system	701	42,0	36
Organic system	698	41,1	29
Mineral system	718	40,4	36

Gluten plays the main role in shaping the baking properties of rye flour. In rye dough, it forms a continuous dispersed phase within which the rest of the substance is contained. Having a certain elasticity, extensibility of gluten, it retains carbon during fermentation, which ensures the proper volume and porosity of bread.

Table 4. **Baking properties of winter rye grain medium (2021–2023)**

Fertilizer system	The amount of gluten, %	Elasticity of gluten, um.od.	Extensibility of gluten, see
Biological control	16,2	99,6	6,9
Organo-mineral system	17,1	85,1	7,8
Organic system	16,7	96,4	7,4
Mineral system	17,3	84,3	8,1

When baking the dough, gluten is denatured and fixes the shape of the bread and the structure of the dough, so there must be enough of it to form a continuous dispersed phase of the dough. The quality of the gluten itself plays no less important role than its quantity. Stronger gluten determines the increased strength of the dough, burdens its extensibility with carbon. Weak gluten is not suitable for forming a protein framework of the necessary strength. It retains carbon quite poorly, and accordingly bread products have poorly developed porosity and a small volume. The largest amount of gluten was obtained with the mineral fertilizer system, which was 17.3%, with the highest stretchability of 8.1 cm, but low elasticity of 84.3. A somewhat lower indicator was obtained for the organo-mineral fertilization system, and was 17.1. The organic system showed the highest gluten elasticity of 96.4, which is slightly less than the control, but in other indicators, the organic system did not show high results.

Energy efficiency in growing winter rye. Each ecological system is characterized by a certain energy exchange, which is provided by two main sources: 1) solar radiation (photosynthesis); 2) oxidation reaction of inorganic substances (chemosynthesis). Moreover, as Braun L points out, the deterioration of the ecological state of the biosphere contributes to the growth of energy consumption in agriculture, while the increase in yield is not significant. Thus, costs in the USA for agricultural production in comparison with 1910. increased 10 times, while the yield increased only twice, in England, the amount of fertilizers applied increased 8 times, and the yield increased by only 50%.

The increase in energy consumption in agro-landscapes under modern conditions is primarily related to the use of energy of anthropogenic origin in the form of labor resources, agricultural machinery, fuel and lubricants, and chemical means of plant protection. The results of research by S.V. Rogalsky, conducted in the forest-steppe zone of Ukraine, note that in the structure of the total energy potential of the studied agricultural landscape, costs of anthropogenic origin amounted to only 0.1% and in retrospect did not exceed 0.2% (at the same time, 30% of the total energy potential was the energy of soil fertility and about 70% – solar energy), their functional influence on production processes remains decisive.

Odum Yu.P. notes that about 40% of the world's arable land is intensively used with high energy costs. According to G. Kant, the main articles of energy consumption are the use of nitrogen fertilizers (43 % of total energy consumption) and fuel and lubricants (29 % of total energy consumption). At the same time, maximum energy savings can be ensured by: biological nitrogen fixation instead of chemical-technical nitrogen fixation; minimization of soil cultivation; biological loosening; reduction of pesticide costs.

In contrast to the monetary assessment, the indicators of energy efficiency are constant and do not depend on subjective factors at all, such as market value, inflation, exchange rate, which gives a real opportunity to estimate exactly the energy costs when growing various agricultural crops under the conditions implementation of soil cultivation technologies and fertilizer standards. At the same time, the main evaluation criterion is the energy efficiency coefficient, which is determined by the ratio of the received mass of energy to the energy consumed.

Table. 5. **Energy efficiency of winter rye growing technology on different fertilization systems, 2021–2023**

Fertilizer system	Yield, t/ha	Total energy spent, MJ	Energy output, MJ	Costs per 1 h, MJ	Energy efficiency coefficient (Kee)
Biological control	2,33	8772,6	61003,7	280,3	6,95
Organo-mineral system	3,24	10128,85	73087,5	270,1	7,21
Organic system	2,71	12804,6	69579,3	358,7	5,43
Mineral system	3,38	14197,6	73672,2	375,6	5,19

The analysis of the obtained results, as can be seen from the table, showed that the highest indicators of the coefficient of energy efficiency were within 7.21, under the conditions of the organo-mineral system, while the lowest indicator was recorded on the mineral system and was 5.19. In our opinion, the reason for this was the sufficiently high energy intensity of mineral fertilizers compared to organic fertilizers, and therefore, despite the highest productivity, it was the mineral system, which amounted to 3.38 t/ha, that the energy consumption indicator was the highest. Therefore, from the energy point of view, we recommend an organo-mineral fertilization system, that is, the simultaneous application of organic fertilizers, and in our case, the after-effect of manure, and the compensation of the need with moderate rates of mineral fertilizers.

Conclusions. As a result of the monitoring and the conducted experiment, it was established that brown leaf rust is the most common and harmful disease in phytocenoses of winter rye, and effective methods of protection are proposed.

1. The greatest yield losses were 8.65% when the development of rust was more than 20%, which was reflected in the weight of 1000 grains, which decreased from 38.7 to 35.4 g. The minimum losses (1.85%) were recorded for the development of rust 5 %, and the largest - 20% and amounted to 8.65%.

2. The lowest development of brown rust was recorded in the variant where crops were sprayed with a mixture of Ajax, KS, 0.5 l/ha and Ekostim-1, RK, 1.5 l/ha, which was 15.4%, which is 13.1% lower than the control.

3. Technical efficiency in the studied options varied from 42.6 to 64.1%. The highest indicators were recorded on the variant of the combined use of Ajax, CS, 0.5 l/ha and Ekostim-1, RK, 1.5 l/ha, which amounted to 64.1%.

4. The maximum yield rate of winter rye was provided by the mixture of Ajax, KS with a consumption rate of 0.5 l/ha and Ekostim-1, RK, 1.5 l/ha, which amounted to 3.6 t/ha, which provided an increase of +1, 3 t/ha, or 56.5%.

5. The analysis of economic efficiency showed that the profitability of the complex application of the plant growth regulator Ekostim-1, RK and the fungicide Ajax, KS at a reduced rate of use was 74.8%, and the net profit was UAH 4,785.8/ha.

6. The highest level of productivity was under the mineral fertilizer system, which amounted to 3.78 t/ha in 2021, showing an average result of 3.38 ha, which is 1.05 t/ha more than the control.

7. The obtained specific weight of 1000 grains gave the highest result on the organo-mineral system of 42.0 g.

8. According to the bread-making properties of the grain, the highest percentage of gluten was obtained from the mineral system of 17.3%, also with its greatest extensibility of 8.1 cm.

9. The highest indicators of the energy efficiency coefficient were obtained under the conditions of the organo-mineral fertilization system, which was within 7.21.