

FORECASTING THE LEVEL OF GROWTH and development of root rots on *Hordeum vulgare* L. plants

Goal. To develop short-term forecasting methods for the seasonal development of root rots of spring barley. **Methods.** The studies were carried out using correlation-regression analysis. Mathematical processing of the obtained data was performed using analysis of variance. **Results.** A high and statistically significant correlation was established between the indicators of spread and development of root rots of spring barley during the study period, as well as during the seasonal development of the disease in individual years. The obtained data show that when forecasting the level of infestation of spring barley with root rots, either one of the two indicators—disease spread or disease development—can be taken into account. The research analysis indicates that the maximum spread and development of root rot depend on the timing of the first visible symptoms. Statistical analysis shows a tendency for decreased spread and development of spring barley root rots when the first symptoms appear later in the season. As a result, the research enabled the development and construction of predictive models that allow determining the spread and development of spring barley root rots during the current season. **Conclusions.** The conducted analysis revealed that based on the average daily positive temperature, it is possible to reliably forecast the level of spread and development of spring barley root rots. Statistical analysis indicates a trend toward decreasing disease spread ($r = -0.44$) and development ($r = -0.70$) with a later onset of the first symptoms. The presented research data and statistical analysis provide comprehensive information on forecasting and regulating the phytopathogenic background in agroecosystems of spring barley, which is essential for modern agricultural production. This enables timely prediction of the onset or changes in the development of root rot diseases in plants.

diseases, mathematical modeling, short-term analysis, phytopathogens

In the 21st century, practically in all branches of science, especially natural and mathematical, it is ef-

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fective to use the modeling method, the creation of which is due to the development of human cognition and is closely related to the transformation of mathematics into a universal language and its penetration into all branches of social sciences. Mathematical modeling in biology at the present stage is one of the most effective methods of research and determination of optimal forms of solving a biological problem, which makes it possible to analyze several characteristics of objects in both static and dynamic modes, while widely using electronic and computing technology [1, 2].

Spring barley is affected by many diseases, mainly parasitic in nature. The crop failure of this crop from a complex of diseases can reach an average of 12 to 18%, and in years of mass reproduction of the pathogen — 50%, sometimes more. The greatest damage to plants is caused by root rots, namely helminthic, fusarium, ophioboloid, pythium,

rhizoctonia and cercosporella root rots [3–6].

Scientists N.N. Loi et al., A.A. Postovalov et al., as well as M. Kharba et al. came to the conclusion that root rots are one of the most numerous and harmful diseases of cereal crops, including bright barley, in all areas of their production [7–11]. For effective control of this type of disease, timely consideration of the features of the development of the disease is essential.

According to T.T. Matengu, P.R. Bullock, M.S. Mkhabela et al., it was studied that modeling the risk of root rots using meteorological data plays an important role in combating crop diseases. Although control of root rot with fungicides reduces yield losses associated with the disease, when weather conditions are unfavorable for disease development, fungicide application can be costly and environmentally undesirable. Thus, fungicides should be used sparingly and only when the pathogen is present and weather conditions are favorable [12, 13].

Forecasting plant diseases is complicated by the fact that it requires considering the dynamics of at least two populations: host plants and pathogens, taking into account the characteristics of soil conditions and meteorological indicators.

There are known attempts to link the course of some crucial stages of the infection cycle and the level of disease development with certain factors or their combination and to use the data to make forecasts [14].

Forecasting the outbreak of a plant disease or its development, infectious and latent periods is in most cases based on regression models that are common in many natural sciences. Thus, any model adequately describes the processes in the area of definition in which its parameters are obtained [15, 16].

Some forecasts are much more accurate if they are based on direct observations in the field conditions of a particular year. Of the large number of elements of the interaction between the host plant and the pathogen that occur in the field, only some of the simplest processes can be reproduced in the laboratory. The presence of two or more pathogens in the field, the additional influence of harmful insects, adverse weather conditions makes significant adjustments to the forecasts [17, 18].

The host plant, pathogen and disease are influenced by factors that interact with each other, as a result of which the effects of both synergy and antagonism may arise. Among such factors, the leading ones are meteorological indicators that determine the susceptibility of plants to infection, the level of pathogenicity of the pathogen, the rate of seasonal development of the host plant, the duration of the incubation period, individual stages of development of the host plant and the disease [19, 20]. Therefore, the basis for predicting the spread of diseases can be informational manifestations of the relationship between the indicators of their development and the factors that influence them. The aim of the work was to develop methods for compiling short-term forecasts of the seasonal development of root rots of spring barley.

Methods. During 2017–2021, the influence of meteorological factors (temperature and soil moisture) on the development of root rot of spring barley was studied at the NUBiP of Ukraine «Agronomic Research Station». Thus, during the research years, weather conditions were favorable for growing the studied crop.

The object of the study was the spring barley variety Avatar (breeding and genetic institute — National center for seed science and variety research of the Ukrainian academy of agrarian sciences).

The soils of the experimental plot are deep low-humus medium-loamy black soil. The humus content in the arable layer is 4.2–4.5%. Agricultural technology is generally accepted for spring barley.

The incidence of spring barley root rot was recorded using a gen-

erally accepted method. 100 plants were dug out from each variant, their root system and stems were washed. In each sample, the number of healthy and affected plants was counted. The severity of the disease was determined visually by examining the basal and root parts of the plants. The counts were carried out in the phases of full germination and tillering. During the growing season, germination energy and field germination were determined on the 3rd, 6th and 9th days.

Prediction of spring barley root rot was carried out using correlation-regression analyses [21, 22].

Before harvesting, in the phase of full ripening, samples of spring barley plants (33 pcs.) were selected and their structural analysis was performed. Harvesting was carried out manually.

As is known, signs of root rot of spring barley appear annually. However, the level of spread and development of the disease varies by plant development phases and years. Due to the cancellation of the ranges of changes in the prevalence and development of root rot in the phases of germination and tillering of spring barley, the concepts of «very high», «high», «medium» or «low» levels of these indicators correspond to different quantitative expressions. Thus, the minimum spread of root rot (45%) of spring barley during the flowering period is not always greater than the maximum spread (45%) during the germination period.

In this regard, the absolute values of the spread and development of root rot were developed by the corresponding scoring scale (Table 1).

A score of 1 was used to assess low levels of disease spread or development, 2 — medium, 3 — high, and 4 — very high. Accordingly, the spread of spring barley root rot in the germination phase up to 15%

should be considered low (score 1), up to 25% — medium (score 2), up to 45% — high (score 3), and from 46 to 50% should be considered a very high indicator (score 4).

At the same time, the level of disease development in the germination phase up to 10% is assessed as low (score 1), up to 20% — should be considered an average level of disease development (score 2), up to 30% — is a high indicator (score 3), and above 30% is considered a very high level of disease development (score 4).

The mathematical processing of the obtained data was carried out by the method of variance analysis [23].

Results and discussion. Short-term forecasting aims to determine the date of appearance, maximum and extinction of epizootics during the season, as well as to determine the expected level of spring barley root rot infestation.

The relationship between the prevalence and development of spring barley root rot was determined depending on the manifestation of the first signs of the disease. According to the results of the study, spring barley root rot has both a high reliable correlation ($r=0.89$) between the indicators of spread and development for the study period from 2017 to 2021, and during the seasonal development of the disease in individual years (from $r=0.79$ in 2017 to $r=0.99$ in 2020) (Fig. 1).

The obtained data indicate that when predicting the level of spring barley root rot infestation, any one of the above indicators can be taken into account — either the spread of the disease or its development.

We also investigated which factors determine the spread and development of spring barley root rot, and to what extent they can be used for prediction (Fig. 2).

Analysis of studies shows that the

1. The value of the indicators of the spread and development of spring barley root rot, corresponding to the score (variety «Avatar», 2017–2021)

Level of distribution and development, points	Disease spread in the seedling phase, %	Disease development in the seedling phase, %
1 — low	≤15	≤10
2 — medium	16 — 25	10 — 20
3 — high	≥26 — 45	≥21 — 30
4 — very high	≥46 — 50	≥30

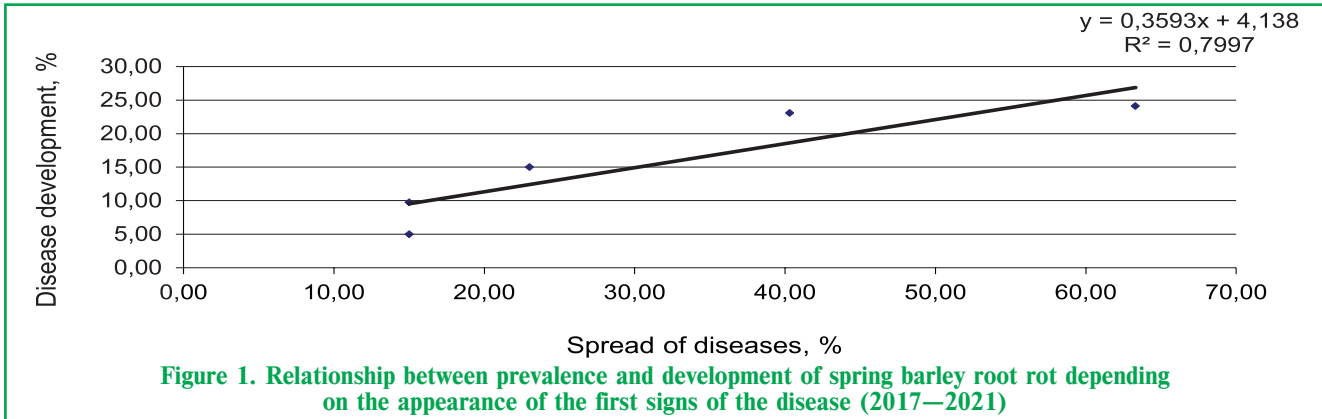


Figure 1. Relationship between prevalence and development of spring barley root rot depending on the appearance of the first signs of the disease (2017–2021)

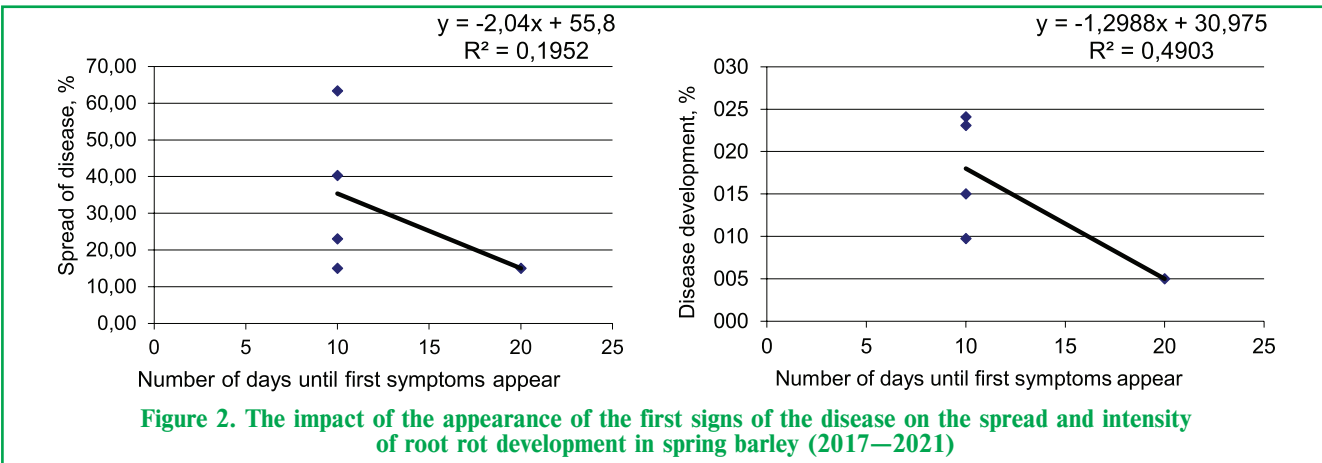


Figure 2. The impact of the appearance of the first signs of the disease on the spread and intensity of root rot development in spring barley (2017–2021)

maximum spread and development of spring barley root rot depend on the date of the first signs of the disease.

Statistical analysis of data from long-term studies shows a tendency to reduce the spread ($r = -0.44$) and development ($r = -0.70$) of spring barley root rot with a later manifestation of the first signs of the disease.

The influence of the timing of the appearance of the first signs of root rot and the sum of average daily temperatures from sowing to the appearance of the first signs of the disease on the spread and develop-

ment of spring barley root rot was also studied (Table 2).

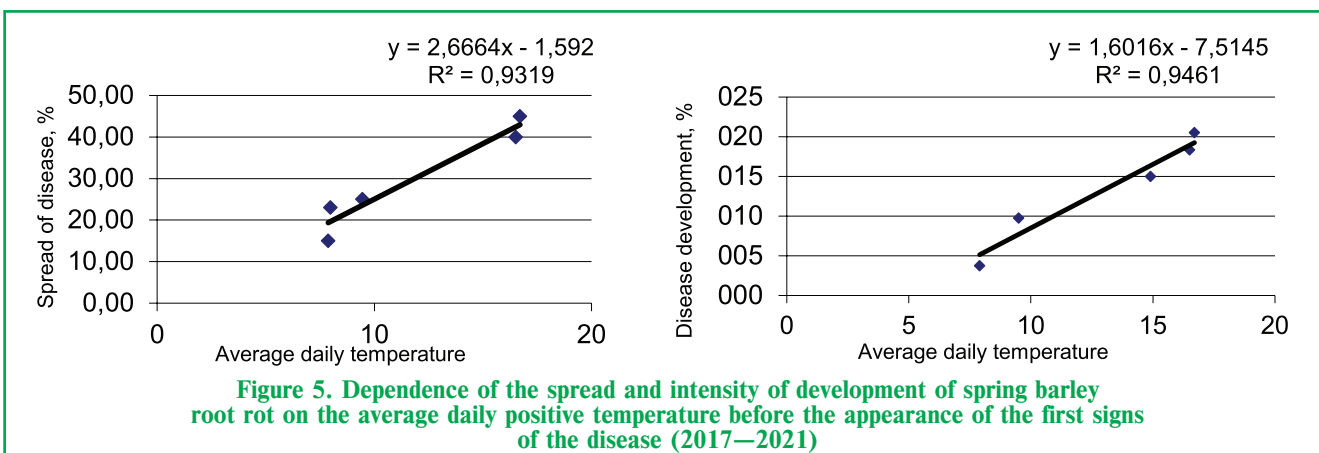
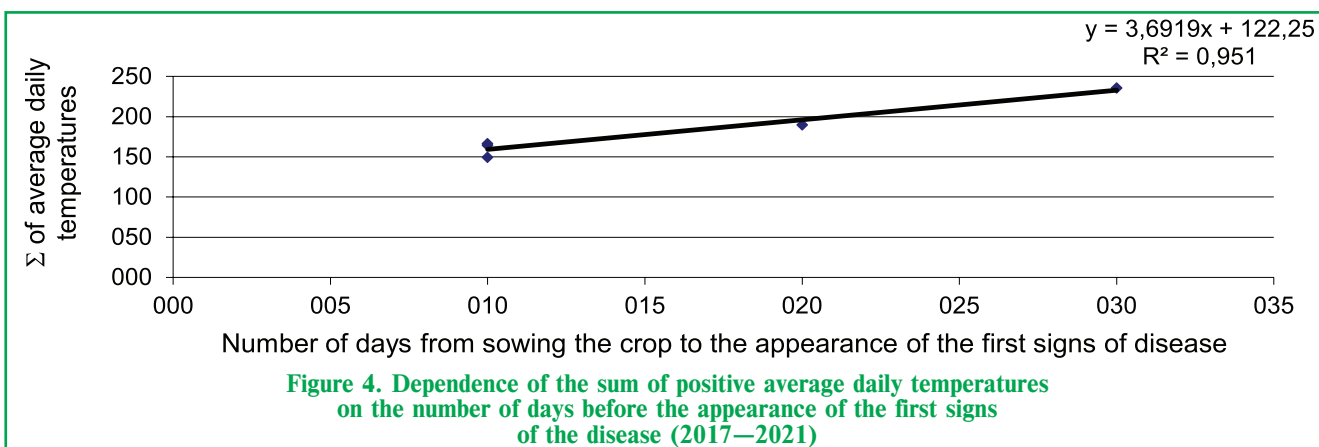
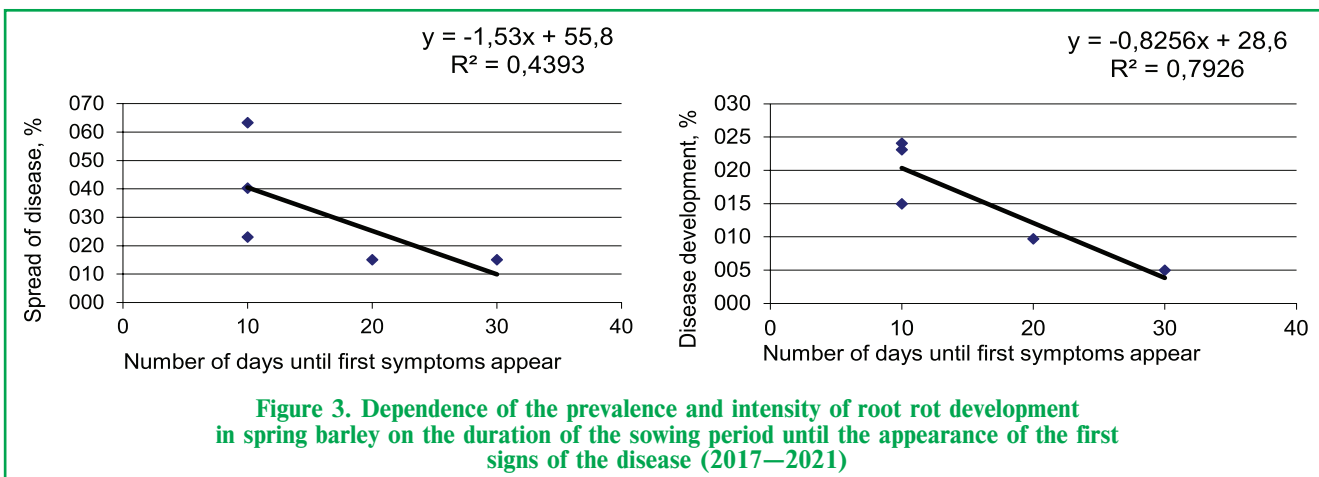
According to the results of the research, it was found that in years with an average score of spring barley seedlings affected by root rot, the first signs of the disease were observed from May 8, 2017 and from May 1, 2021, where their indicators were 23% and 25%, respectively. Therefore, 20 days passed from sowing to the appearance of the first signs of plant disease in both 2021 and 2017. And in years with a low score of spring barley seedlings affected by root rot, the first signs of

the disease were observed on May 12, 2020, where the indicator was 15% (30th day after sowing). At the same time, a high score of spring barley seedlings affected by root rot was recorded from April 29, 2018 and from April 25, 2019, where the indicator was 45% and 40%, respectively. And from sowing to the appearance of the first signs of plant disease in both 2018 and 2019, 10 days passed after sowing. So, in years with a low score of spring barley seedlings affected by root rot, its first signs were observed from May 12, 2020, namely on the 30th day after sowing, and with a high score — from April 29, 2018 and April 25, 2019 (10 days after sowing). At the same time, the results of the research showed that the spread and development of spring barley root rot were lower in years when the manifestation of signs of the disease was observed later. If, with a low disease development score, the first signs of manifestation were observed on May 12, 2020 and May 01, 2021, where the indicator was 3.75% and 9.75% (30th day after sowing and 20th day, respectively), then with a high di-

2. The influence of the timing of the appearance of the first signs of the disease and the sum of the average daily temperatures from sowing to the appearance of the first signs of the disease on the spread and development of root rot in spring barley (variety «Avatar», 2017–2021)

Sowing dates	Time of appearance of the first signs of the disease	Number of days from sowing to first signs	Σ from sowing to the appearance of the first signs of disease	Seedlings	
				Affected plants, %	Disease development, %
18.04.2017	8.05.2017	20	189,9	23	15,25
19.04.2018	29.04.2018	10	164,6	45	20,5
15.04.2019	25.04.2019	10	166,8	40	18,5
12.04.2020	12.05.2020	30	236,1	15	3,75
11.04.2021	01.05.2021	20	159,5	25	9,75

Note: Σ — sum of average daily temperatures



sease development score, the first signs of manifestation were noted on April 29, 2019, where the indicator reached 20.5%, namely on the 10th day after sowing. At the same time, with an average disease development score on spring barley plants, the first signs of manifestation were noted on May 08, 2017, with an indicator of 15.25% (20th day after sowing), and on June 25, 2019, with an indicator of 18.5% (10th day after sowing) (Table 2). Thus, the prevalence of root rot was higher with a longer duration of signs of spring

barley disease. On average, the duration of the plant infection period was up to 50 days, in years of severe infection — up to 60, and in years of mild infection — up to 40 days. The dependence of the prevalence and intensity of root rot development in spring barley on the duration of the period from the moment of sowing the crop to the appearance of the first signs of the disease was determined. Thus, statistical analysis of data for 5 years shows that the prevalence and intensity of root rot development in spring barley was higher when the

first signs of the disease appeared before 10 days than before 30 days ($r = -0.66$; $r = -0.88$). (Fig. 3).

Statistical analysis of the dependence of the prevalence and intensity of root rot development in spring barley on the duration of the period from the moment of sowing the crop to the appearance of the first signs of the disease shows close direct correlations.

We also investigated the dependence of the sum of positive average daily temperatures on the number of days until the appearance of the first

signs of the disease on spring barley plants (Fig. 4).

The results of the study showed that the more time passed from sowing to the appearance of the first signs of the disease, the higher the accumulated sum of average daily positive air temperatures during the studies ($r = 0.97$).

The dependence of the prevalence of root rot on the average daily positive temperature until the appearance of the first signs of the disease was established (Fig. 5).

The results of statistical analysis show that the prevalence of spring barley root rot depended on the positive average daily air temperature, which accumulated until the date of the first signs of the disease ($r = 0.88$).

A similar relationship was established between the intensity of root rot development from the average daily positive temperature until the moment of the first signs of the disease (Fig. 5).

Statistical analysis showed an even closer direct correlation between the intensity of root rot development and the average daily temperature, which accumulated until the date of the first signs of the disease ($r = 0.97$).

Correlation analysis made it possible to build predictive models by which it is possible to determine the spread and development of spring barley root rot in the current season, namely: $Y1 = 2.6889X - 5.6246$, for the spread of the disease; $Y2 = 1.6016X - 7.5145$, for the intensity of the disease.

Therefore, the conducted research and statistical analysis make it possible to predict and regulate the phytopathogenic background in agroecosystems of spring barley plants, to predict the onset or change in the severity of root rot diseases. The introduction of predictive models for determining the spread and development of spring barley root rot will make it possible to reduce the harmfulness of the disease and improve the quality of the crop.

CONCLUSIONS

The analysis shows that the average daily positive temperature can be used to reliably predict the level

of spread and development of spring barley root rot. Thus, the maximum spread and development of spring barley root rot depend on the date of the first signs of the disease. Statistical analysis of data from long-term studies shows a tendency to reduce the spread ($r = -0.44$) and development ($r = -0.70$) of spring barley root rot with a later manifestation of the first signs of the disease.

Therefore, the presented research materials and statistical analysis allow us to have a comprehensive knowledge of the prediction and regulation of the phytopathogenic background in agroecosystems of spring barley plants, which is a useful and integral part of modern agricultural production, which allows us to predict the onset or change in the severity of root rot diseases.

The implementation of predictive models for determining the spread and development of spring barley root rot will make it possible to reduce the harmfulness of the disease and improve the quality of the harvest, increasing the ecological safety of agroecosystems.

Funding: The research was conducted in accordance with the state theme: «Theoretical and methodological justification of the use of new potential antifungal agents — derivatives of nitrogen-containing heterocycles» (DR No. 0116U001604, 2016-2018); «Substantiation of the concept of creating steel urbo-phytocenoses with increased resistance to biotic and abiotic factors» (DR No. 01170002644, 2019).

Conflict of interest: the authors declare the absence of a conflict of interest regarding the presented research materials and statistical analysis in the article.

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Прогнозування розвитку кореневих гнилей на рослинах *Hordeum vulgare* L.

Мета. Розробити методики складання короткострокового прогнозування сезонного розвитку кореневих гнилей ячменю ярого. **Методи.** Дослідження проводили за допомогою кореляційно-регресійних аналізів. Математичну обробку отриманих даних здійснювали методом дисперсійного аналізу. **Результати.** Встановлено високу достовірну кореляцію між показниками поширення та розвитку кореневих гнилей ячменю ярого за період дослідження, а також і впродовж сезонного розвитку хвороби в окремі роки. Одержані дані свідчать, що при прогнозуванні рівня ураженості ячменю ярого кореневими гнилями можна брати до уваги будь-який один із зазначених показників — або поширення хвороби, або її розви-

ток. Аналіз досліджень свідчить, що максимальне поширення та розвиток кореневої гнилі ячменю ярого залежать від дати прояву перших ознак хвороби. Статистичний аналіз даних свідчить про тенденцію до зниження поширення та розвитку кореневої гнилі ячменю ярого за більш пізнього прояву перших ознак хвороби. Отже, проведені дослідження дали змогу розробити та побудувати прогностичні моделі, за якими можна визначити поширення та розвиток кореневої гнилі ячменю ярого в поточному сезоні. **Висновки.** Проведений аналіз виявив, що за даними середньодобової позитивної температури можна достовірно прогнозувати рівень поширення та розвитку кореневої гнилі ячменю ярого. Статистичний аналіз даних свідчить про тенденцію до зниження поширення ($r = -0,44$) та розвитку ($r = -0,70$) кореневої гнилі ячменю ярого за пізнішого прояву перших ознак хвороби. Наведені матеріали дослідження та статистичний аналіз дають комплексну інформацію щодо прогнозування та регулювання фітопатогенного фону в агроценозах рослин ячменю ярого. Це важливо для сучасного аграрного виробництва і дозволяє передбачити початок або зміну розвитку кореневої гнилі на рослинах.

хвороби; математичне моделювання; короткостроковий аналіз; фітопатогени

Received by the editorial office:

March 26, 2025

Accepted for publication: April 3, 2025

Printed and published online: June 2025