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RESEARCH ARTICLE
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Impact of Soil Tillage Practices on Disease Development in Winter Wheat

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ABSTRACT

Winter wheat is a strategic food crop in many countries. This crop is susceptible to a wide range of pathogens that can cause yield losses of up to 50-100%. The most important element in obtaining a high-quality harvest is properly selected soil cultivation, since it directly ensures favorable water, nutrient, and thermal conditions, as well as good aeration. The aim was to evaluate the effectiveness of soil cultivation methods in winter wheat cultivation against fungal diseases. The research was conducted in the experimental fields of the Federal Research Center of Biological Plant Protection (FRCBPP) in Krasnodar, Russia, in 2022-2023. The experimental plots included two technologies - non-moldboard and moldboard tillage. The manifestation degree of the primary pathogens of leaf and root diseases of winter wheat was compared in experimental plots. The study revealed that the growth of phytopathogens on the non-moldboard tillage plot was higher than on the moldboard one. Thus, in 2023, climatic conditions favored the growth of pathogens. As a result, the incidence of powdery mildew was 3.3 times higher, yellow spot - 1.5 times, septoria - 1.3 times, and root rot - 1.2 times. The economic efficiency on the moldboard tillage plot was also higher, amounting to 6.45 t ha-1, whereas that on the non-moldboard tillage plot was 5.11 t ha^{-1}. In 2024, no apparent effect of soil cultivation methods on disease development was found in the experimental plots. This is due to weather conditions and low pathogen growth. However, the impact of cultivation on crop yield was clearly visible. The yield on the moldboard tillage plot was t ha-1; on the non-moldboard one - 3.66 t ha-1. We can conclude from this research stage that moldboard tillage has several advantages, including reducing the incidence of winter wheat diseases and increasing grain yield.

Keywords: Non-moldboard and Moldboard tillage; Winter wheat; Leaf pathogens; Root rots; efficiency; Yield.

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INTRODUCTION

The UN Food and Agriculture Organisation (FAO) assumes food production must increase by an estimated 70% by 2050 to meet the needs of the world's growing population (Food and Agriculture Organization of the United Nations (FAO), 2011). However, land degradation, declining soil fertility, unsustainable water use, overfishing and marine degradation are all reducing the potential of the natural resource base (Food and Agriculture Organization of the United Nations (FAO), 2011). Wheat diseases significantly reduce grain yield and grain quality. Thus, rust pathogens leaf and stripe rust cause yield losses of up to 50-70% (Figueroa et al., 2018; Volkova et al., 2021). Tan spot and septoria pathogens lead to a decrease in yield of up to 40-60% (Kokhmetova et al., 2017; Kremneva et al., 2019; Shankar et al., 2021; Volkova et al., 2021). Wheat diseases worldwide are managed using chemical (Gaile et al., 2023), biological (Kremneva et al., 2021; Asaturova et al., 2022) and agrotechnical methods (Sabitov & Sharipova, 2015). Agrotechnical methods are of great importance in the overall system of plant protection measures. However, for a long time, agrotechnical methods were underestimated (Ponomarev et al., 2022). The advantage of agrotechnical control methods, along with variety genetics, is their efficiency in increasing plant damage resistance. The environmental impact of agriculture can promote unfavorable conditions for the spread of specific diseases. For example, moldboard tillage can reduce the incidence of tan spot by half because the soil is turned over during tillage.

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This, in turn, creates unfavorable conditions for pathogen growth (Pleskachev et al., 2013; Sakhibgareev & Garipova, 2015; Bankina et al., 2021). In addition, the degree of damage by root rot is reduced by 1.10-1.25 times when using moldboard tillage compared to the non-moldboard one (Beloshapkina & Akimov, 2016; Kozlova et al., 2016; Apaeva & Manishkin, 2017; Dolbilova et al., 2017; Tsilurik, 2019; Feng et al., 2021). Some researchers (Beloshapkina & Akimov, 2016; Tsilurik, 2019) note the advantage of moldboard tillage as one of the means of combating pathogens of winter wheat; the role of agricultural technology in this regard is very important. Southern Russia is the main area for winter wheat cultivation and provides up to 20% of the gross grain harvest in Russia. This crop is exposed to a wide range of harmful pathogens (phytopathogens, phytophagous insects, weeds), which can lead to yield losses of up to 50-100% (Illarionov, 2019; Pushnya et al., 2020; Pachkin et al., 2022; Savva et al., 2022).

Apart from the records of moldboard plow tillage, Hu et al. (2021) documented that reduced tillage alleviated ecological risks of plant pathogens with inefficient transformation by producing about 32.3% bacterial-fungal interactions (32.3%) in the rhizosphere soils. Chen et al. (2023) reported that tillage practices had minimal influence on pathogens Rhizoctonia solani and Streptomyces scabies. On the other hand, Nikitin et al. (2023) concluded that cultural practices such as crop rotation and intensive tillage promote pathogen suppression, while long-term monoculture and no-till cultivation in most circumstances lead to the accumulation of phytopathogenic microorganisms. Even though soil tillage has a well-established impact on crop performance and disease development, nothing is known about how particular tillage techniques impact the intricate relationship between climatic variability and winter wheat pathogen incidence, especially in southern Russia's dynamic agroclimatic conditions.

Numerous studies have established that moldboard tillage, which involves inverting the soil and burying plant residues, can significantly reduce the prevalence of key fungal diseases and root rots compared to non-moldboard or no-till systems based on the principles that compaction of the soil inhibits the growth of roots, increases oxygen deprivation, and may facilitate the spread of pathogens that cause root diseases (Syromyatnikov et al., 2023). Kremneva et al. (2021) displayed that moldboard tillage reduced the spread of leaf rust pathogens and powdery mildew pathogens when compared to other tillage systems. However, a large portion of this literature only discusses specific agroecological zones and neglects to methodically account for yearly climate variations, which are becoming more and more significant in light of climate change. Additionally, the combined effects of tillage methods and seasonal weather on pathogen dynamics and yield results are rarely examined in the literature in high-production areas like Krasnodar Krai, which accounts for a sizable portion of Russia's grain production. Although studies have demonstrated the agronomic advantages of conventional tillage, they do not offer a comprehensive examination of pathogen variation from year to year or the financial effects of disease control measures (Tsyliuryk et al., 2025). The lack of integrated, multi-seasonal data, especially in areas with significant interannual weather variability, hinders the creation of strong, flexible cultivation guidelines. Thus, by examining the effects of moldboard versus non-moldboard tillage on the emergence of economically important pathogens during two distinct growing seasons, 2023 and 2024, in Krasnodar, this study closes a critical gap. This work offers a more thorough understanding of how tillage interacts with environmental factors to affect crop health and productivity by integrating in-depth meteorological analysis and evaluating disease manifestation and yield. The results show moldboard tillage's superior ability to slow the spread of disease during pathogen-favorable weather, as well as its ability to maintain yield benefits even in the absence of disease pressure (Ualiyeva, 2024).

These results highlight the need for context-specific agrotechnical approaches that address climatic and biological factors. Thus, this study adds important empirical data in favor of economically and environmentally sound adaptive disease management strategies, which are in line with international initiatives to maintain food security in the face of growing climate uncertainty. By bridging existing gaps between disease ecology, tillage methods, and local weather variability, this study enhances the practical relevance of soil management practices and strengthens the scientific foundation for policy recommendations in winter wheat agroecosystems (Спичак et al., 2024).

The most important element in obtaining a high-quality harvest is properly selected soil cultivation (Pleskachev et al., 2013; Ponomarev et al., 2022), since it directly ensures favorable water, nutrient and thermal conditions, as well as good aeration. Some research papers mention that the yield of winter wheat with mold-board tillage is 1.3-1.5 times higher than that with the non- moldboard one (Pleskachev et al., 2013; Sabitov & Sharipova, 2015; Sakhibgareev & Garipova, 2015). Moldboard tillage creates optimal conditions for the growth of agricultural crops. Conventional technologies for growing grain crops, due to production and environmental conditions, do not fully ensure high profitability. Therefore, improving existing technologies and searching for new ones to obtain economically viable products is a pressing issue for both Russia and other wheat-producing countries. Here we aim to study the influence of soil tillage on the development of economically significant pathogenic microorganisms causing leaf and root rots in winter wheat.

MATERIALS & METHODS

The research was conducted during the cultivation of winter wheat of the Alekseich variety in the experimental fields of the Federal Research Center of Biological Plant Protection (FRCBPP), Krasnodar (45° 2.413′ 0″ N, 38° 58.5598′ 0″ E, 29m above sea level) in 2021-2023. The experiment was repeated four times. The size of the experimental plot: length – 100 m, width 14m. The variants of the applied treatments: moldboard method with the plough PLN-3-35 to a depth of 22-25cm; non-moldboard method with the harrow BDT-3 to a depth of 10-12cm.

The soil cover in the research area is characterized by leached mycelial-carbonate chernozem (deep leached chernozem) with a slightly acidic reaction (pH 5.5–6.5). Loose soil-forming rocks are clayey and heavy loamy. Humus in the arable soil layer is humate; it makes up 3.0–4.5%, gradually decreasing with depth. Total nitrogen content is 0.20%, mobile phosphorus – 18.2mg/100 g of soil, and exchangeable potassium – 30.6mg/100g. The climate of the region under study is moderate continental, with sufficient moisture and light during the long growing season. The weather of the 2022-2023 growing season (Fig. 1) was slightly characterized by lower precipitation. However, the relative air humidity was higher than the long-term average throughout the season, ranging from 76.6 to 88.6%. Spring temperatures ranged from 8.6 to 16.5℃, which is higher than the long-term average. During this season, the manifestation of powdery mildew and tan spot was noted. A fairly high development of leaf rust was observed towards the end of the growing season. The spring period of the 2023-2024 growing season (Fig. 2) was characterized by low precipitation and low relative humidity compared to the average long-term values. Air temperatures in the spring period ranged from 7.4 to 18.7℃. Thus, the 2023-2024 growing season was the warmest and driest in comparison with previous years of research. Such weather promoted the development of rust diseases of wheat and tan spot. Pre-sowing seed treatment was carried out on October 12, 2022 and October 18, 2023. All subsequent manipulations to protect the crop were carried out in accordance with the adopted technology for protecting winter wheat in the crop development phases such as tillering, filling, flag leaf, earing-milky-wax ripeness. During this period, a broad-spectrum microbiological fertilizer with fungicidal and stimulating properties Geostim Fit grades A, B, C, D, E, and G was introduced, as well as a humic fertilizer - 10% liquid concentrate of the dry powder preparation "Gumel-Lux". Sowing of winter wheat of the Alekseich variety in 2022 was carried out on October 13 and October 19, 2023 at a rate of 4million/ha at a depth of 5-6cm. The growing season in 2023 lasted until July 7 and amounted to 267 days. Germination energy was 96%; laboratory germination was 97% in plots with two tillage methods. The vegetation period in 2024 lasted until July 5 and was 259 days. Germination energy was 98%; laboratory germination was 100% in plots with two tillage methods. The study visually assessed the development of leaf diseases of winter wheat and root rot during active vegetation of the crop from March to June 2023 and 2024. The following economically significant pathogens of leaf and root diseases of winter wheat were selected: tan spot (*Pyrenophora tritici-repentis*), septoria leaf spot (*Zymoseptoria tritici*), powdery mildew (*Blumeria graminis*), leaf and stripe rust (*Puccinia triticina*, *P. striiformis*) and root rot (*Bipolaris sorokiniana*, *Fusarium spp*.).

Disease manifestation was recorded in the main phases of the growing season: the "tillering" phase Z 29-32, the "stemming" phase Z 37-39, the "earing" phase Z 51-59, the "milky-wax ripeness" phase Z 71-82. Root rot was recorded in the "tillering" phase Z 29-32 and the "milky-wax ripeness" phase Z 71-82 (Zadoks et al., 1974). During each of these developmental phases, 30 plant samples were collected in quadruplicate along the diagonal of each experimental plot. In this case, disease symptoms were taken into account on each tier of the plant (the first tier is the bottom leaf; the second tier is the subsequent one, and so on). Severity of tan spot, septoria and powdery mildew was scored as a percentage according to the Saari and Prescott scale (Babayants et al., 1988).

The incidence of root rot was recorded in the "tillering" phase Z 29-32 and the "milky-wax ripeness" phase Z 71-82. Thirty plants were selected from each experimental plot in four copies. The root rot pathogen was identified by fragmenting the roots and bases of the stems of the affected plants (Babayants et al., 1988; Zadoks et al., 1974). The plants were uprooted; the stem base was cleared of leaves, and the assessment was carried out according to the darkening of the stem surface (%) at the level of the root collar (Koishybaev & Mumindzhanov, 2016). The root rot intensity was assessed in points and calculated using the following formula (1) (Koishybaev & Mumindzhanov, 2016).

$$R=(\sum nd)/NK*100\ \% \qquad (1)$$

R – development of the disease, %;
$\sum nd$ – the sum of the products of the number of diseased plants by the number;
N – total number of plants analyzed;
K – the highest score on the scale.

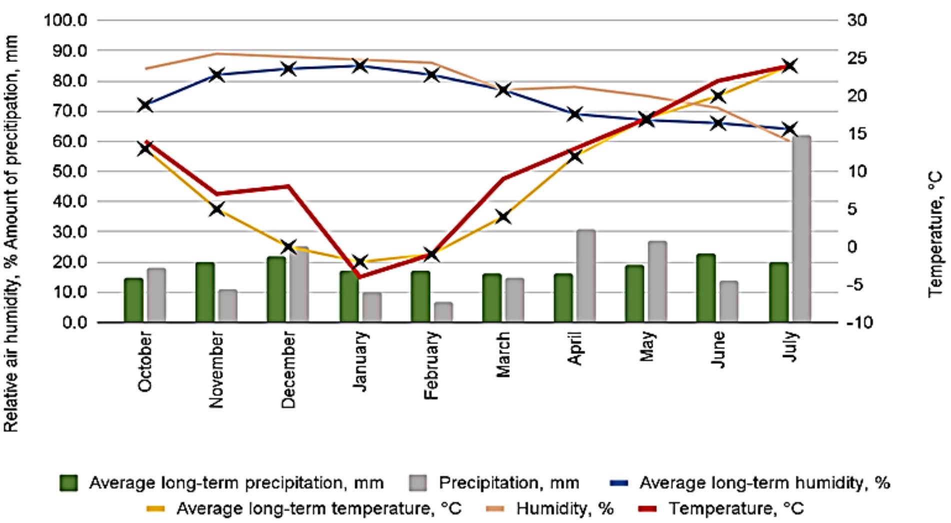

Fig. 1: Weather of the 2022-2023 growing season, Kruglik weather station, (FRCBPP), Krasnodar.

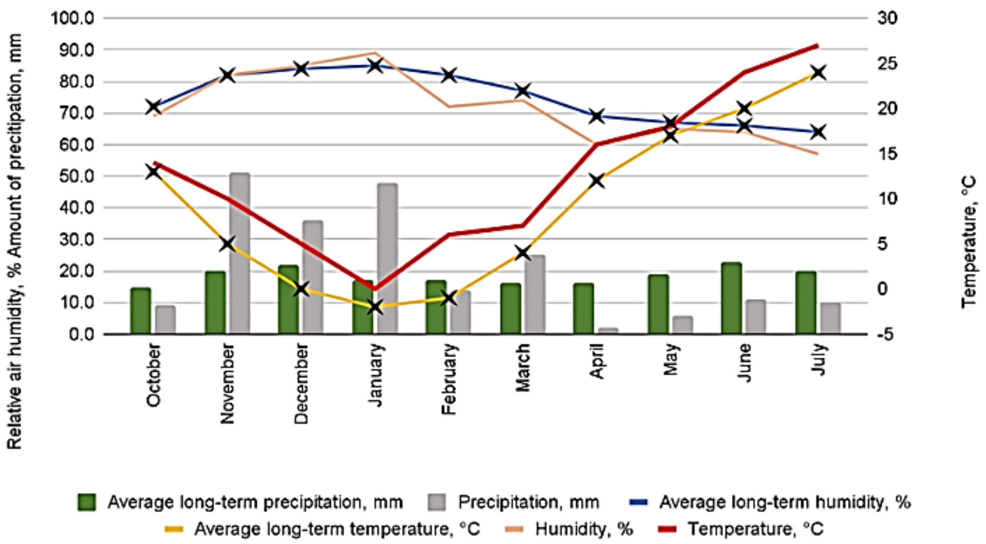

Fig. 2: Weather of the 2023-2024 growing season, Kruglik weather station, (FRCBPP), Krasnodar.

The economic efficiency of technologies with different methods of soil cultivation was assessed in accordance with the "Field Experiment Methodology" (Dospehov, 2013). The reliability of differences between samples was checked using the Statistica 2010 program. The yield structure was deter-mined according to methodological recommendations (Dospehov, 2013; Ulyanov & Knyazeva, 2017). Calculations of the reliability of differences in the obtained data were carried out using Duncan's Multiple Range test (Dospehov, 2013). Economic efficiency - the entire experimental plot was harvested by direct combining.

RESULTS

The following pathogens of leaf and root diseases of winter wheat were recorded during the 2023-2024 research: tan spot (*P. tritici-repentis*), septoria leaf spot (*Z. tritici*), powdery mildew (*B. graminis*), leaf and stripe rust (*P. triticina*, *P. striiformis*) and root rot (*B. sorokiniana*, *Fusarium spp.*). According to the results of a two-way analysis of variance of pathogen growth depending on tillage methods and year conditions (Table 1), the most pronounced effect of soil cultivation (factor A) on pathogen growth was noted. Weather peculiarities in 2023-2024 (factor B), as well as the combined influence of these factors (A and B) were less significant. The development of root rots in the two growing seasons differed greatly (Fig. 3). Disease manifestation in 2023 in the non- moldboard tillage plot was 60.80 %. In the moldboard tillage plot – 49.17%; this was preceded by heavy precipitation above the long-term average in April and May. In 2024, the development of root rot in all experimental plots was insignificant and much lower than in 2023. Since the amount of precipitation was significantly less than the long-term average.

According to the obtained results, the development of root rot in the non-moldboard tillage plot was 0.08%. In the moldboard tillage plot – 0.14%. The development of leaf diseases in the two growing seasons also differed greatly (Fig. 4). Powdery mildew was noted in the studied crops only in 2023. The disease developed most intensively in the Z 40-47 phase; and in the non-moldboard tillage plot it reached 9.65%. Since the average annual precipitation rate was exceeded. In the moldboard tillage plot, this Fig. was 2.85%. In the following phases of vegetation, a single manifestation of the pathogen was noted.

Table 1: Results of two-way analysis of variance of the dependence of pathogen growth on soil cultivation methods in 2023–2024

Phase	Pathogen	A	B	AB
Z 40-47	*Blumeria graminis*	49.0*	14.50*	14.50*
	Pyrenophora tritici-repentis	102.01*	0.71	0.06
	Zymoseptoria tritici	1.05	1.28	1.98
Z 51-59	*Blumeria graminis*	13.2*	0.41	0.41
	Pyrenophora tritici-repentis	41.69*	24.57*	10.50*
	Zymoseptoria tritici	75.99*	4.51*	3.07
Z 61-69	*Blumeria graminis*	6.41*	0.03	0.03
	Pyrenophora tritici-repentis	39.52*	2.19	4.15*
	Zymoseptoria tritici	69.68*	0.02	2.72
	Puccinia striiformis	42.65*	0.00*	0.00*
	Puccinia triticina	156.12*	6.27*	6.27*
Z 75	*Blumeria graminis*	4.22*	0.00	0.0
	Pyrenophora tritici-repentis	36.99*	0.42	2.92
	Zymoseptoria tritici	219.81*	0.21	2.03
	Puccinia striiformis	104.63*	0.03	0.03
	Puccinia triticina	3.06	3.06	3.06

* the factor influences the growth of the pathogen ($F_f > F_{crit.}$; where $F_{crit.}$=3.97; P=0.05); Factor A – soil cultivation; Factor B – weather.

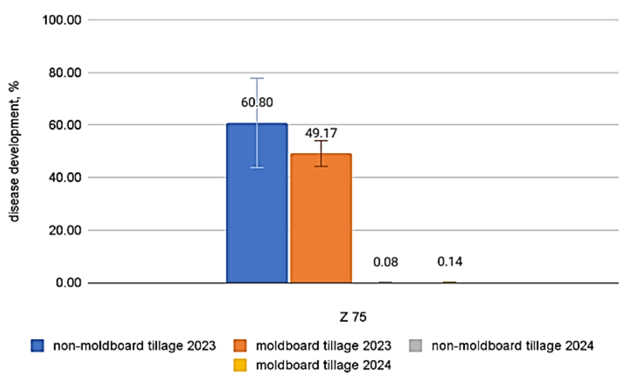

Fig. 3: Development of root rot in winter wheat crops using two tillage methods in 2023–2024; Note: Data included in one group (Latin letters) do not have reliable differences according to Duncan's criterion at the 95% significance level.

Tan spot was observed in experimental crops in two growing seasons (Fig. 5). The maximum disease manifestation in 2023 was noted in the wheat development phases Z61-69 and Z 75. In the non- moldboard tillage plot, the maximum disease manifestation was 8.53%; in the moldboard tillage plot - 6.63%. In 2024, the maximum disease manifestation in the non- moldboard tillage plot was noted in the Z 51-59 phase and amounted to 2.85%. The maximum disease manifestation in the moldboard tillage plot was reached in the Z 75 phase and amounted to 3.21%. Septoria was detected in both 2023 and 2024 (Fig. 6). The maximum disease manifestation in 2023 was noted in the Z 40-47 phase. In the plot with non-moldboard tillage, the development was 5.91%; but 4.57% in the plot with moldboard tillage. In 2024, the maximum disease manifestation was noted in the Z 75 phase. In the plot with non-moldboard tillage - 6.36%; with the moldboard one - 6.97%.

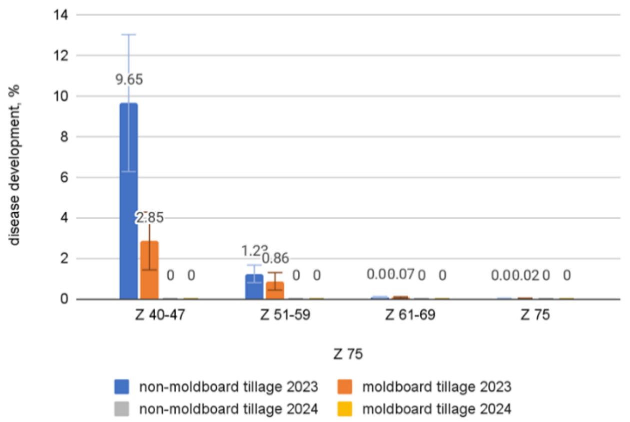

Fig. 4: Powdery mildew development in winter wheat crops using two tillage methods in 2023–2024; Note: Data included in one group (Latin letters) do not have reliable differences according to Duncan's criterion at the 95% significance level.

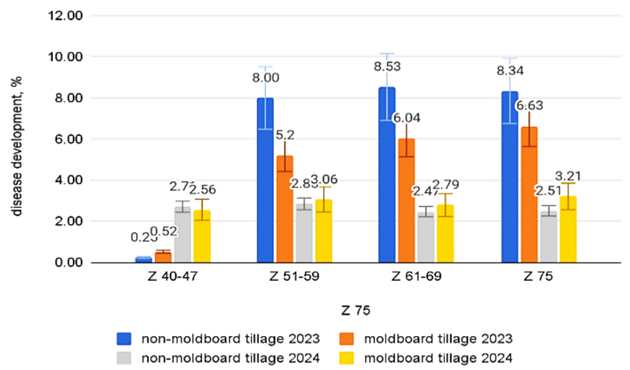

Fig. 5: Tan spot development in winter wheat crops using two tillage methods in 2023–2024; Note: Data included in one group (Latin letters) do not have reliable differences according to Duncan's criterion at the 95% significance level.

Stripe rust was detected in the studied crops only in 2024 (Fig. 7) due to favorable weather conditions for this pathogen. The maximum manifestation was detected in the Z 75 phase. In the plot with non-moldboard tillage, the disease development was 2.44%. In the plot with moldboard tillage - 2.53%. Leaf rust was detected only in 2024 in a plot with moldboard tillage in the development phases Z 61-69 and Z 75. The manifestation of the disease was insignificant and amounted to 0.17 and 0.07% (Fig. 8). Fig. 9 shows the yield of winter wheat obtained as a result of research in 2023 and 2024. The economic efficiency on the plot with moldboard tillage was higher both in 2023 and in 2024. This is due, among other things, to weather conditions in 2024. As a result, the difference in species composition and intensity of disease development in the years of research is clearly traced. However, the assessment of the development of leaf diseases and root rot on plots with different tillage methods showed a clear advantage of moldboard soil cultivation practices.

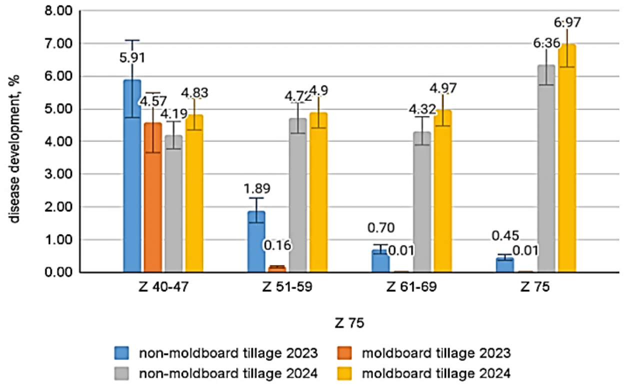

Fig. 6: Septoria development in winter wheat crops using two tillage methods in 2023–2024; Note: Data included in one group (Latin letters) do not have reliable differences according to Duncan's criterion at the 95% significance level.

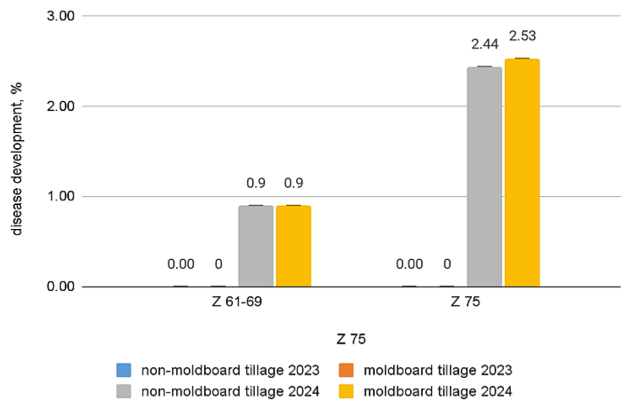

Fig. 7: Stripe rust development in winter wheat crops using two tillage methods in 2023–2024; Note: Data included in one group (Latin letters) do not have reliable differences according to Duncan's criterion at the 95% significance level.

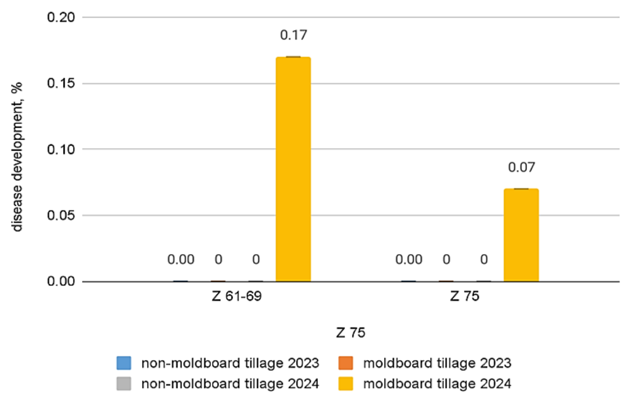

Fig. 8: Leaf rust development in winter wheat crops using two tillage methods in 2023–2024; Note: Data included in one group (Latin letters) do not have reliable differences according to Duncan's criterion at the 95% significance level.

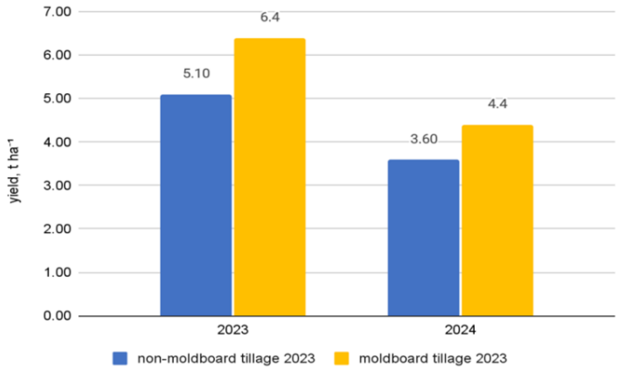

Fig. 9: Winter wheat yield using two tillage methods in 2023–2024.

DISCUSSION

As a result of the studies of moldboard and non-moldboard methods of soil cultivation, the development of such diseases as powdery mildew, tan spot, septoria, leaf and stripe rusts and root rot was noted. The analysis of pathogen growth on the experimental plots showed a clear advantage of the moldboard method. The manifestation degree of tan spot in the plot with non-moldboard soil cultivation was 1.5 times higher. These results aligned with the studies of Woźniak et al. (2023) and Kozulina and Vasilenko (2021), they concluded that the manifestation of pathogens were 1.5 times lower in moldboard method than in direct sowing for both spring wheat and winter wheat crops thereby highlighting the climate resistant trait of the moldboard tillage practice. Similar data were obtained in the studies by Latvian scientists, who describe the influence of moldboard and non-moldboard methods of soil cultivation on the manifestation of this pathogen (Bankina et al., 2021). The article states that with moldboard tillage, the pathogen distribution was 2 times lower compared to the non-moldboard one. Ploughing reduced the impact of previous crops since moldboard tillage involves soil turnover, destroying some pathogens. Similar research has been conducted in Denmark to study the effects of *Pyrenophora tritici-repentis* on winter wheat. Field experiments confirmed that moldboard tillage was more effective than other tillage methods (Jorgensen & Olsen, 2007).

In our studies, septoria manifestation over the entire research period was 1.3 times higher in the plots without any soil cultivation. A number of Russian studies compare different soil cultivation practices and describe their impact on disease development. Thus, in Kirov, the incidence of septoria in grain crops was low: 3.2–7.0%. Non-moldboard tillage increased stem susceptibility and reduced wheat yield by 0.31 t ha-1 (NCP05A = 0.29) compared to the moldboard one (Kozlova et al., 2016). In Krasnoyarsk Krai, a positive effect of moldboard tillage on reducing the incidence of septoria was recorded. The strongest septoria manifestation was observed when wheat was grown instead of maize on unfertilized land without any tillage (31.3%). This is 16.8% more than with conventional primary tillage (Puchkova et al., 2021).

The incidence of root rot was 1.2 times higher with moldboard tillage. Similar studies were conducted in the Russian Federation and other countries. In Dnepropetrovsk, the degree of damage by root rot decreased on plots with moldboard tillage by 1.10–1.25 times, as well as without the addition of fertilizers compared to the treated ones. This occurs due to plowing of plant residues and reduction of the period of plant infection as a result of their premature ripening and drying out (Beloshapkina & Akimov, 2016; Apaeva & Manishkin, 2017; Dolbilova et al., 2017; Tsilurik, 2019). Root rot control methods were also examined in tropical and subtropical highland areas of the world. The study presents two types of tillage: conventional and no-till. Wheat grown without tillage was found to have a significantly higher incidence of root rot than wheat grown on a plot with moldboard tillage (Govaerts et al., 2007). In agreement with the obtained results, Kozulina et al. (2023) also observed the lower incidence of root rot conidia than with minimal tillage and zero sowing and highlighted that the factors such as soil activity, seasonal drought, nutrient deficiency, immature seeds, and deep seed embedding during sowing contributed to the susceptibility to root rot. Thus, in 2023 climatic conditions favored pathogen growth. As a result, the incidence of powdery mildew was 3.3 times higher, tan spot - 1.5 times, septoria - 1.3 times, and root rot - 1.2 times. The economic efficiency on the moldboard tillage plot was also higher and amounted to 6.45 t ha^{-1}; that on the non-moldboard tillage plot was 5.11 t ha^{-1}. In 2024, no obvious effect of soil cultivation methods on disease development was found in the experimental plots. This is due to weather conditions and low pathogen growth. However, the effect of cultivation on crop yield was clearly visible. The yield on the moldboard tillage plot was 4.40 t ha^{-1}; on the non-moldboard tillage plot - 3.66 t ha^{-1}. We can conclude at this research stage that moldboard tillage showed a number of advantages, both in reducing the development of winter wheat diseases and in increasing grain yield. Recent studies such as Szczepanek et al. (2023) have established that the response of yield components and wheat grain yield to simplifications in tillage is fundamentally reliant on meteorological circumstances in a study year. Contrary to the results of the study, Semenikhina et al. (2021) concluded that no-tillage system displayed better performance in terms of the moisture-temperature regime of the soil and the yield of winter wheat when compared to other tillage practices.

The efficiency of moldboard tillage is confirmed by the obtained yield - 6.45 t ha^{-1} in 2023 and 4.40 t ha^{-1} in 2024; non-moldboard tillage - 5.11 t ha^{-1} in 2023 and 3.66 t ha^{-1} in 2024. This fact has been confirmed in some other studies. For example, studies by Chinese and Moroccan scientists show that crop yields were higher with moldboard tillage (Wafae et al., 2023; Yan et al., 2023). European scientists observed the highest yield and the most favorable values of physiological indicators with moldboard soil cultivation technique (Buczek et al., 2021). According to the findings of Pakistani researchers, the highest yields were recorded in conventionally cultivated plots. Moldboard tillage yielded the highest grain yield with a 1000-kernel weight of 52g compared to 35g in non-moldboard tillage (Sanaullah et al., 2023). In this study, moldboard tillage showed several benefits, both in reducing leaf diseases and root rot, and in increasing grain yield by 26.2% in 2023 and 18.2% in 2024. Despite the positive results for moldboard tillage, numerous limitations in this study should be addressed. Firstly, the study had just two years of data, during which climatic variability played a substantial role in disease development. The atypically dry 2024 season limited the expression of numerous diseases, potentially influencing the consistency and strength of the conclusions reported. Secondly, while pathogen identification and disease severity ratings were thoroughly done, the study relied mainly on visual scoring methods and did not include molecular or microbiological confirmation procedures, which could have improved pathogen specificity and detection accuracy. Additionally, there is a lack of a full soil health assessment that goes beyond basic nutrient composition and pH levels. Soil microbial communities, organic matter content, and compaction levels, all known to influence plant health and pathogen dynamics, were not assessed and may have confusing effects.

Furthermore, economic efficiency was assessed without taking into account inputs such as fuel consumption, labor, and environmental effect assessments. Future research should include longer-term, multi-site experiments with various wheat genotypes, as well as integrated disease evaluation methods such as remote sensing and genomic techniques. Expanding the scope to incorporate no-till systems, cover cropping, and biological soil additives may provide more insights into long-term disease suppression techniques. A comprehensive systems-level approach would enable a better understanding of how tillage methods interact with soil ecology, crop physiology, and disease epidemiology under various climate conditions.

Conclusion

Based on the field experiments conducted in 2023 and 2024, the following conclusions can be drawn. In the agroclimatic conditions of Krasnodar Krai, winter wheat is exposed to a complex of harmful pathogens, including some phytopathogens. Chemical pesticides negatively impact the environment and lead to the development of resistance in harmful organisms. Therefore, improving existing technologies and searching for new ones to obtain economically profitable, including organic, products is a pressing issue. In this regard, the reduction of phytopathogens of winter wheat is possible with the help of agricultural techniques. Since they directly affect the soil, providing it with water, nutrition and heat, as well as good aeration. To achieve a high-quality, ecologically clean harvest, it is essential to select the primary soil cultivation method correctly. The results of the studies showed the effectiveness of the moldboard tillage against a complex of winter wheat diseases, as well as increasing the yield in Krasnodar Krai (Russian Federation). These studies will be continued over the next 3 years to obtain reliable results and identify the influence of a complex of factors.

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