On the issue of the advisability of the autumn application of nitrogen fertilizers for winter rye (*Secale cereale* L.)

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Abstract. The article presents the results of studying the effect of autumn application of mineral nitrogen fertilizers on winter hardiness of winter rye plants. The relevance of research is due to the search for opportunities to reduce the anthropogenic load on the environment, in particular by minimizing the use of artificial fertilizers. The studies were carried out for three years in the fields of the North-West region of the Russian Federation, on medium-cultivated sod-podzolic loamy soils. Sowings of winter rye were placed on the predecessor, early potatoes, under which organic fertilizers were applied for the main tillage. Experimental plants of winter rye were fed on seedlings with ammonium nitrate; in the control, autumn fertilizing was not used. The experimental results showed that the autumn application of nitrogen fertilizers practically did not affect the percentage of successfully overwintered plants. This allows us to conclude that the autumn use of nitrogen fertilizers for winter rye is inexpedient and that it is possible to abandon their autumn use in order to reduce environmental pollution.

1. Introduction

At present, due to the increasing anthropogenic load on the environment, the question of the possibility of minimizing the use of mineral fertilizers in the fields is relevant. In particular, the possibility of changing the traditional scheme of nitrogen fertilization of winter crops is being considered. Until now, for winter rye, it was recommended to apply fractional nitrogen fertilizers: 1/3 of the total dose in autumn for pre-sowing treatment or when shoots appear, 2/3 in spring when regrowth begins [1]. This scheme was developed in accordance with the traditional concept that with a lack of nitrogen, winter rye plants stay underdeveloped before winter and survive winter worse. It is believed that the aftereffect of nitrogen fertilizers applied under the previous crop is absent, especially on soils with a pronounced leaching regime [2].

One of the main processes ensuring the winter hardiness of winter crops is the accumulation of sugars in them during the autumn hardening [3]. It was shown that with the autumn pre-sowing application of nitrogen fertilizers, there was a tendency to an increase in the sugar content in plants, but within the experimental error. At the same time, the percentage of successfully overwintered plants did not change in comparison with the control [4]. Other researchers have shown that the autumn application of nitrogen fertilizers increased the sensitivity of winter crops to frost [5], while winter triticale was shown to increase plant safety with the autumn application of nitrogen fertilizers [6]. In other experiments with winter rye, wheat, and triticale, the winter hardiness of these crops was determined mainly by the species, and within one culture it was weakly dependent on the level of...
nitrogen nutrition [7]. Thus, the beneficial effect of the autumn application of nitrogen fertilizers for winter crops is questionable.

It is known that the use of mineral fertilizers can lead to adverse environmental consequences in the form of a significant change in the acid-base state of soils and environmental pollution. Thus, ammonium and even ammonium-nitrate forms of nitrogen fertilizers have an acidifying effect [8, 9], which is especially unfavorable for acidic soils. The use of nitrate forms of nitrogen fertilizers can lead to excessive accumulation of nitrates in the soil and their entry into water bodies and aquifers. It is known that plants do not completely consume nitrogen from mineral fertilizers, depending on weather conditions, from 2.6% to 90.7% of nitrogen introduced with mineral fertilization can be used [8]. In this case, the excess of ammonium nitrogen quickly transforms into the nitrate form due to the processes of nitrification, followed by the washing out of nitrates from the soil [2]. It has been shown that nitrate ions, due to their high mobility, are found in groundwater and in water bodies already after 1-3 months [10]. Thus, during the autumn application of nitrogen fertilizers, there is a risk of nitrate pollution of water sources, especially in rainy and cold autumn, when the consumption of nitrogen by plants is reduced and the leaching regime is increased.

In the presented study, the influence of the autumn application of mineral nitrogen fertilizers, according to the traditional scheme, on the winter hardiness of winter rye plants was studied. The aim of the research was to identify the possibility of adjusting the traditional scheme of feeding winter rye in accordance with modern trends on environmental safety in the Agroindustrial Complex.

2. Materials and Methods
The studies took three years and were performed in the Gatchinsky district of the Leningrad region of the North-West region of the Russian Federation on the experimental fields of the “Belogorka” Leningrad Research Institute of Agriculture. The soil in the experimental fields was sod-podzolic, loamy, medium-cultivated with a plow horizon depth of 20-25 cm. The humus content was 2.0-2.3%, the pH of the salt extract was 5.2-5.5. Organic fertilizers based on chicken manure were applied under the early potato predecessor, under the main soil cultivation at a dose of 30 t/ha. Sowing of winter rye was carried out in the first ten days of September by hand with a seeding rate of 300 pcs/m². Nitrogen fertilizers in dry form were applied to seedlings in the form of ammonium nitrate at a dose of 30 kg/ha of active ingredient in nitrogen, which was 1/3 of the total dose of nitrogen fertilizers for the entire growing season. In the control, nitrogen fertilizers were not used.

The research was carried out on three varieties with different types of short stems: variety Volkhova had the recessive type of short stems, variety Dana had dominant type of short stems, variety Eureka had dominant recessive type of short stems.

The winter hardiness of plants was accounted for by directly counting the number of plants per 1 m² before overwintering and after it; the difference is presented as the percentage of overwintered plants from the number of those that left before winter. The experimental setting procedure and statistical processing of the experimental results were carried out as described [11].

3. Results and Discussion
As a result of the studies, it was found that the autumn application of ammonium nitrate did not have a practical effect on the winter hardiness of various varieties of winter rye, as can be seen from Tables 1, 2 and 3. Since ammonium nitrate contains nitrogen in both ammonium and nitrate forms, it can be said that that both of these forms of mineral nitrogen had no effect on the degree of overwintering of the studied culture.

It should be noted that overwintering conditions varied greatly in the years under study. The autumn-winter period of 2017-2018 was distinguished by a cold, excessively rainy autumn, the plants before winter were poorly developed, as a result of which there was a significant loss of crops. The winter of 2019 was characterized by a high snow cover, which protected the plants from freezing, but contributed to damping off, while the safety of plants by the spring was at an average level. The winter of 2020 was distinguished by a very mild nature, a complete absence of snow cover and the absence of
severe frosts throughout the entire winter period, which contributed to the good survival of plants.

Table 1. The degree of overwintering of winter rye plants, depending on the availability of autumn feeding, Eureka variety

| Variant                        | Repetition | Number of overwintered plants (%) |       |       |       |
|-------------------------------|------------|-----------------------------------|-------|-------|-------|
|                               |            |                                   | 2018  | 2019  | 2020  |
| With autumn application of ammonium nitrate | 1          | 51.7                              | 79.1  | 83.0  |
|                                | 2          | 40.1                              | 72.2  | 89.3  |
|                                | 3          | 47.6                              | 75.0  | 83.6  |
| Mean                          |            |                                   | 46.5  | 75.0  | 85.3  |
| σ                             |            |                                   | 4.8   | 2.8   | 2.8   |
| v (%)                         |            |                                   | 10.3  | 3.8   | 3.3   |
| Without autumn application of ammonium nitrate | 1          | 52.6                              | 73.3  | 77.6  |
|                                | 2          | 56.7                              | 79.5  | 77.4  |
|                                | 3          | 48.5                              | 71.8  | 78.6  |
| Mean                          |            |                                   | 52.6  | 74.9  | 77.9  |
| σ                             |            |                                   | 3.3   | 3.3   | 0.5   |
| v (%)                         |            |                                   | 6.4   | 4.5   | 0.7   |
| f_{obs}.                      |            |                                   | 2.2   | 0.1   | 13.3  |
| f_{cr} (0.05)                 |            |                                   | 7.7   | 7.7   | 7.7   |

Nevertheless, despite the different wintering conditions, in none of the study years was there a clear effect of the autumn application of mineral nitrogen on the winter hardiness of winter rye. Only in 2020, with an uncharacteristically warm winter for the North-West region of Russia, the Eureka variety, according to the results of statistical analysis, showed a slightly greater survival rate when feeding with ammonium nitrate in autumn, as can be seen from Table 1. That year, autumn growth lasted several weeks longer than usual, which could enable the slowly developing variety Eureka at the first stages, in the presence of autumn nitrogen feeding, to have more developed plants compared to the control, which better tolerated negative return temperatures in the complete absence of snow cover.
The varieties Volkhova and Dana, which grew faster at the first stages of development, also showed a similar trend, as can be seen from Tables 2 and 3, however, the difference between the variants, according to the results of statistical analysis, was not reliable.

In 2018, the difference between the options was not in favor of applying nitrogen mineral fertilizers for all varieties, but this difference was also not statistically significant.

It should be noted that in the studies carried out, winter rye was cultivated according to its predecessor, under which only organic fertilizers were applied for the main filling of the soil. It is known that nitrogen-containing organic matter in the soil is a slow-acting buffer system in relation to nitrogen [2]. Probably, it was the introduction of organic matter under the previous crop that fully provided the winter rye plants with the necessary amount of nitrogen for the period of autumn development.

Table 3. Degree of overwintering of winter rye plants depending on the availability of autumn feeding, Dana variety

| Variant                        | Repetition | Number of overwintered plants (%) | 2018 | 2019 | 2020 |
|--------------------------------|------------|-----------------------------------|------|------|------|
| With autumn application of ammonium nitrate | 1          |                                   | 43.8 | 70.7 | 79.2 |
|                                 | 2          |                                   | 31.7 | 78.9 | 87.8 |
|                                 | 3          |                                   | 47.6 | 75.5 | 81.6 |
| **N**                          |            |                                   | 41.0 | 75.4 | 82.9 |
| **σ**                          |            |                                   | 6.8  | 3.4  | 3.6  |
| **ν (%)**                      |            |                                   | 16.5 | 4.5  | 4.4  |
| Without autumn application of ammonium nitrate | 1          |                                   | 44.8 | 74.1 | 73.0 |
|                                 | 2          |                                   | 53.4 | 78.1 | 78.6 |
|                                 | 3          |                                   | 35.6 | 71.3 | 85.2 |
| **N**                          |            |                                   | 44.6 | 74.5 | 78.9 |
| **σ**                          |            |                                   | 7.3  | 2.8  | 5.0  |
| **ν (%)**                      |            |                                   | 16.3 | 3.8  | 6.3  |
| f_{obs.}                       |            |                                   | 0.3  | 0.1  | 0.8  |
| f_{cr} (0.05)                  |            |                                   | 7.7  | 7.7  | 7.7  |

4. Conclusion

As the results of our research have shown, when growing winter rye on a precursor fertilized with organic matter, the autumn application of mineral nitrogen fertilizers did not have any significant effect on the degree of overwintering of rye in all years of study. In this case, neither weather factors nor varietal affiliation played a special role. Given the potential danger of nitrate ions unused by plants entering groundwater and water bodies, especially during cold rainy weather in autumn, we question the feasibility of the traditional autumn application of nitrogen fertilizers for winter rye in the northern regions and see an opportunity to abandon their use in the autumn period, especially on soils well-filled with organic matter.

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