Influence of fertilizers on harvest yield, uptake of nutrients, and "raw" protein content in winter rye grains of Vologda region

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Abstract. Based on results of the research done during 2017–2019 on the sod-podzolic medium loamy soil of the Vologda region, when applying the estimated doses of fertilizers $N_{90}P_{40}K_{100\text{-}120}$ we can achieve 67–79% increased yields of winter rye grains compared to the control. When applying fertilizers with the dose $N_{12}P_{16}K_{16}$, yield of winter rye straw increases by 25%. With full estimated doses of fertilizer $N_{90}P_{40}K_{100\text{-}120}$, straw yields increase by 74–87% compared to control. Uptake of nutrients of 1 ton of winter rye with respective amount of straw when applying estimated doses of fertilizers compared to control, increases by 4 kg for nitrogen, 3–4 kg for potassium and does not change for phosphorus. With $N_{12}P_{16}K_{16}$, the "raw" protein is increased by 0.4% in absolute units or 3% in relative units compared to control, and with $N_{90}P_{40}K_{100\text{-}120}$ –by 1.8–2.0% in absolute units or by 16-17% in relative units.

1 Introduction

In Russia, winter rye covers an area of about 3 million hectares [1], and in the Vologda region - about 2,000 hectares [2]. Although winter rye is a plant that has adapted well to the conditions of the North-Western region of Russia and its modern varieties yield 3.5 tons/ha and more [2–4], the area of its cultivation is declining.

Scientifically founded doses of fertilizers in crop rotations can solve the problem of increasing crop productivity, taking into account the level of soil fertility and agronomic effectiveness of doses of fertilizers [2–6].

A number of studies have shown that the full estimated doses of fertilizers on the sod-podzolic medium loamy soil of the Vologda region increase the uptake of nitrogen and potassium by the main agricultural product taking into account its by-products and do not affect the uptake of phosphorus compared to the variant without fertilizers [2–4]. Fertilizers increase the content of "raw" protein both in the main and in by-products [6, 7].

Therefore, the questions of optimization of the doses of fertilizers are relevant. The goal of the research is to study the impact of different doses of fertilizers on the yield of the main and by-products, nitrogen, phosphorus and potassium uptake and the content of "raw" protein in the grain of winter rye in the Vologda region. The object of research are fertilizers of winter rye of the *Volkhova* variety.

2 Research methodology

The research was carried out on the experimental field of the FSBEO HE Vologda State Dairy Farming Academy in a long field stationary experience – crop rotation, deployed in space and in time. The experiment has been laid down and conducted since 1990. The article presents the results of the latest 3-year studies (2017 to 2019).

The experiment is conducted using the 4-field crop rotation scheme: vetch-oat mix, winter rye of the *Volkhova* variety, potatoes, barley. The experimental scheme for winter rye during 2017–2019 was: a variant without fertilizers – control (1); a variant with fertilizers applied at the sowing stage (2); two variants of the studied mineral fertilizer systems, differing in the balance coefficient of the use of potassium from

Table 1. Yield of winter rye grains when applying fertilizers, t/ha.

No	Variant	2017	2018	2019	Average	Increase compared to control	
						t/ha	%
1	No fertilizer (control)	2.44	1.90	2.17	2.17	-	-
2	$N_{12}P_{16}K_{16}$	2.87	2.31	2.88	2.69	0.52	24
3	$N_{90}P_{40}K_{100}$	3.68	3.57	3.65	3.63	1.46	67
4	$N_{90}P_{40}K_{120}$	4.03	3.89	3.76	3.89	1.72	79
5	$N_{90}P_{35}K_{85}$	3.74	3.69	3.62	3.68	1.51	69
Least Significant Difference$_{05}$		0.52	0.69	0.73			

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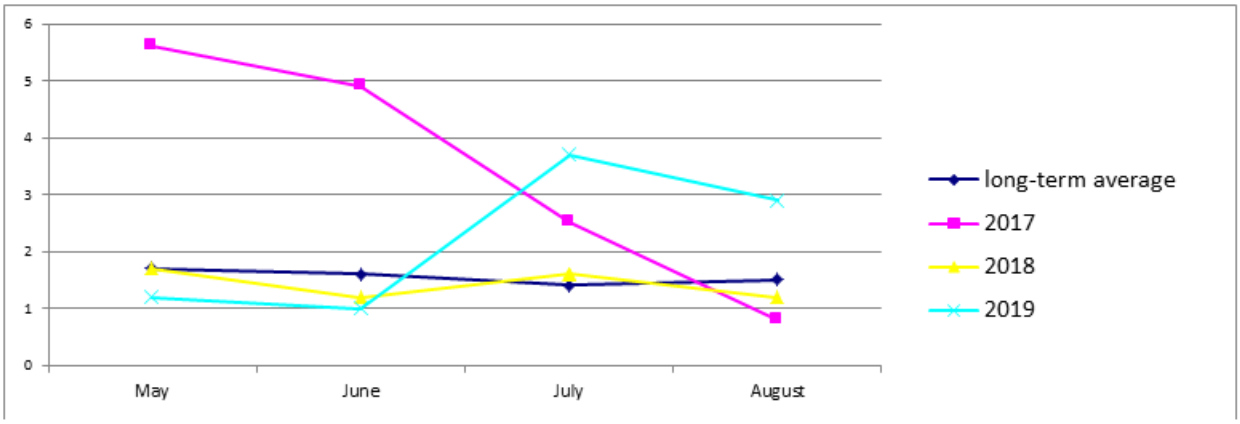

Fig. 1. Monthly HTCs during 2017, 2018, and 2019 compared to long-term average values.

fertilizers and soil (Bc) (3, 4) and a variant of organic-mineral system (5), equivalent by its elements to the variant 3. For all the variants in the experiment, we have planned a negative balance of nitrogen (Bc = 120%) and zero balance of phosphorus (Bc = 100%). For potassium, in the variants 3 and 5, zero balance is planned, and in the variant 4 – a positive one (see table 1).

Doses of fertilizer were calculated for the planned yield of 3.5 tons/ha of winter rye grains according to the planned Bc as the ratio of the product of the planned balance ratio and the uptake of nutrients to 100%, according to Yu.P. Zhukov [5].

The soil of the experimental field is sod-podzolic medium loamy. The arable layer before the 6th crop rotation (after 20 years of research) was characterized by the medium acidic reaction of the environment (pH_{KCl} = 4.9) of the control sample, the contents of mobile phosphorus and exchange potassium were respectively 132 and 55 mg/kg of soil, humus content – 2.56%.

The technology of cultivating winter rye used in the experiment was the one common in the Northwestern zone. Phosphorous and potassium mineral fertilizers were applying during plowing in the form of double superphosphate and potassium salt. In the 2nd variant, a minimum dose of fertilizer was studied – when sowing, complex NPK fertilizer was applied, calculated for 1 c/ha of physical weight. In the variants 3, 4 and 5 during sowing we have applied $N_{12}P_{16}K_{16}$, $P_{19\text{-}24}$, $K_{69\text{-}106}$ as double superphosphate and potassium salt into the main fertilizer, N_{18} was applied during pre-sowing plowing, and N_{60} was added to the top-dressing. Semi overdone manure in the variant 5 in a dose of 40 t/ha was added when we were growing potatoes; only its post-effects were studied for winter rye. Sowing was done in late August and early September. The experiment was repeated four times. The fields were positioned in a complicated systematic pattern, the area of each was 140 m^2, and their dimensions – 10 m by 14 m.

In the analysis of the commodity and non-commodity parts of the harvests after wet ashing according to K. Ginzburg, we have determined the contents of: nitrogen according to Kjeldahl, phosphorus on a photocolorimeter, potassium on a flame photometer. Mathematical processing of these data was carried out by the method of one-factor dispersion analysis with the help of computers according to B.A. Dospekhov (1985) [8].

According to the FSBI "Vologda Center for Hydrometeorology and Environmental Monitoring" (SMS Vologda), vegetation periods of 2017 and 2019 were characterized by low temperature and excess moisture, especially in July, and frequent heavy rains. Despite sharp temperature fluctuations in October to December, and late snow cover in the autumn-winter periods of 2016-2017, 2017-2018, 2018-2019, winter rye plants of the *Volkhova* variety overwintered well, at 91 and more percent of seedlings. Weather conditions, despite deviations from long-term average values, had a good effect on growth, development, and the state of winter rye crops, providing high yields during years of research. Figure 1 shows the hydrothermal wetting coefficients (HTC) during May and summer months of research years compared with long-term averages calculated as the ratio of the amount of precipitation in millimeters at temperatures above + 10 ° C, multiplied by 10, to the sum of active temperatures for the same period in degrees Celsius (according to G.T. Selyaninov).

3 The results of research and their discussion

The use of fertilizers increased the yield of the winter rye grain. The minimal dose of fertilizers was insignificantly increasing the yield of winter rye grain during 2017–2019 years of research. Application of calculated doses of fertilizers (variants 3 to 5) in all years of research significantly increased the yield of winter rye grains compared to both the option without fertilizer and the one with a minimum dose of fertilizer (table.1).

Equivalent in nutrients mineral and organic-mineral systems (variants 3 and 5), and all the calculated doses of fertilizers did not differ in their effect on the yield of winter rye grains. That is, the increase in the introduced doses of potassium fertilizer from 100 to 120 kg a.i./ha does not significantly increase the yield of crops. The maximum harvest yield of winter rye of 4.03 t/ha in

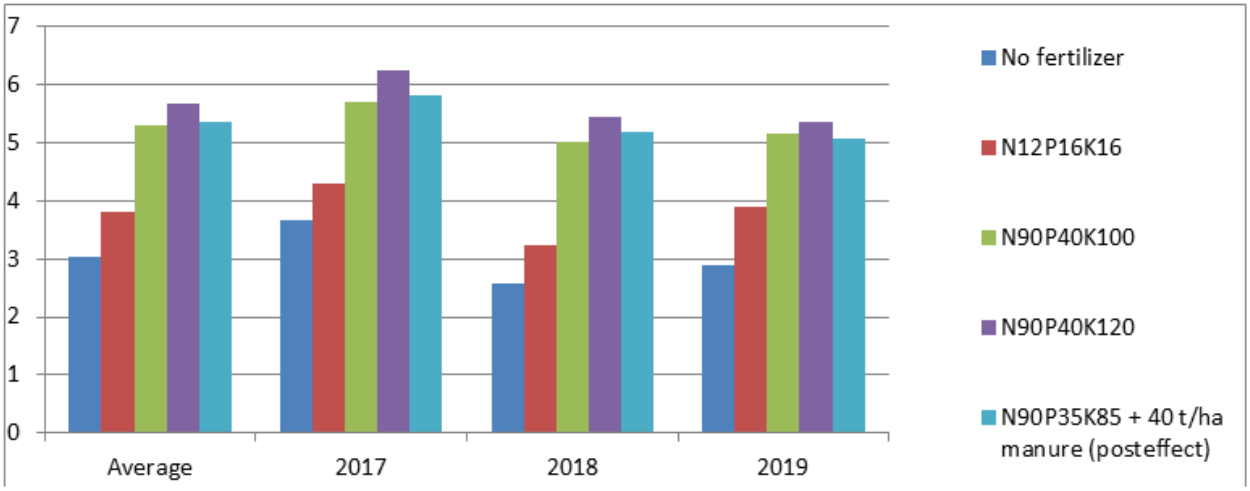

Fig. 2. Harvest yields of winter rye straw when applying fertilizers during 2017–2019, t/ha.

2017 (with the average of 3.88 t/ha during the 3 years) was obtained in the variant 4, when using the maximum dose of potassium fertilizer. On average, over the years of research, calculated doses of fertilizers (variants 3 to 5) increased the yield of winter rye grains by 67 to 79 % compared to control.

The application of fertilizers, both in minimal and calculated doses, increased the yield of by-products – the winter rye straw. This increase on average during the years of research amounted to 0.77–2.64 t/ha, or 25 to 87 %. Increasing the dose of potassium fertilizer from 100 to 120 kg a.i. (variant 4 vs. variant 3) caused an increase in straw yields by 7.6% (Figure 2).

The uptake of nutrients by 1 ton of winter rye grain with the respective amount of straw when using calculated doses of fertilizer increased compared to the control for nitrogen – by 3kg, potassium – by 3 to 4 kg, and did not change for the phosphorus (table 2).

Table 2. Uptake of nutrients by 1 ton of grain with the respective amount of straw when using fertilizers, kg.

Variant	Nitrogen	Phosphorus	Potassium
Planned costs	30	12	28
Control (no fertilizer)	28	11	19
$N_{12}P_{16}K_{16}$	28	11	22
$N_{90}P_{40}K_{100}$	31	11	22
$N_{90}P_{40}K_{120}$	31	10	23
$N_{90}P_{35}K_{85}$ + 4-year post effect of 40 t/ha of overdone manure	32	11	23

The highest uptake of nitrogen by 1 ton of grain, taking into account the straw, of winter rye, was when using calculated doses of fertilizers (variants 3 to 5). De-facto, uptake of nutrients by winter rye in variants 3 to 5 was slightly higher, for nitrogen – about 1 to 2 kg higher than planned, for phosphorus and potassium it was lower, respectively, by 1 to 2 and 4 to 5 kg.

The content of "raw" protein in the winter rye grain increased slightly with the use of a minimum dose of

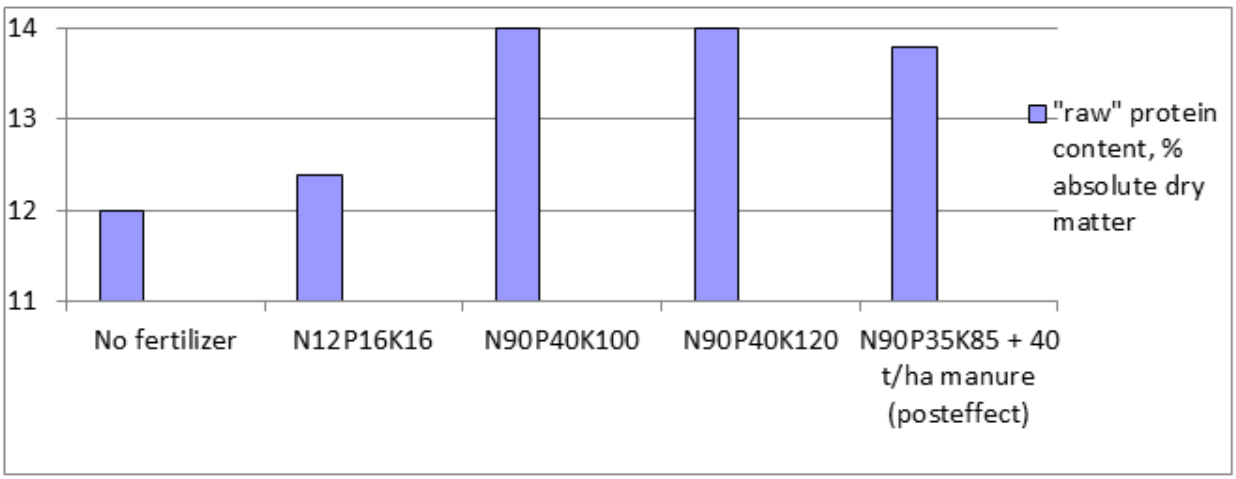

Fig. 3. Content of “raw” protein in the winter rye grain, on average during 2017–2019, %.

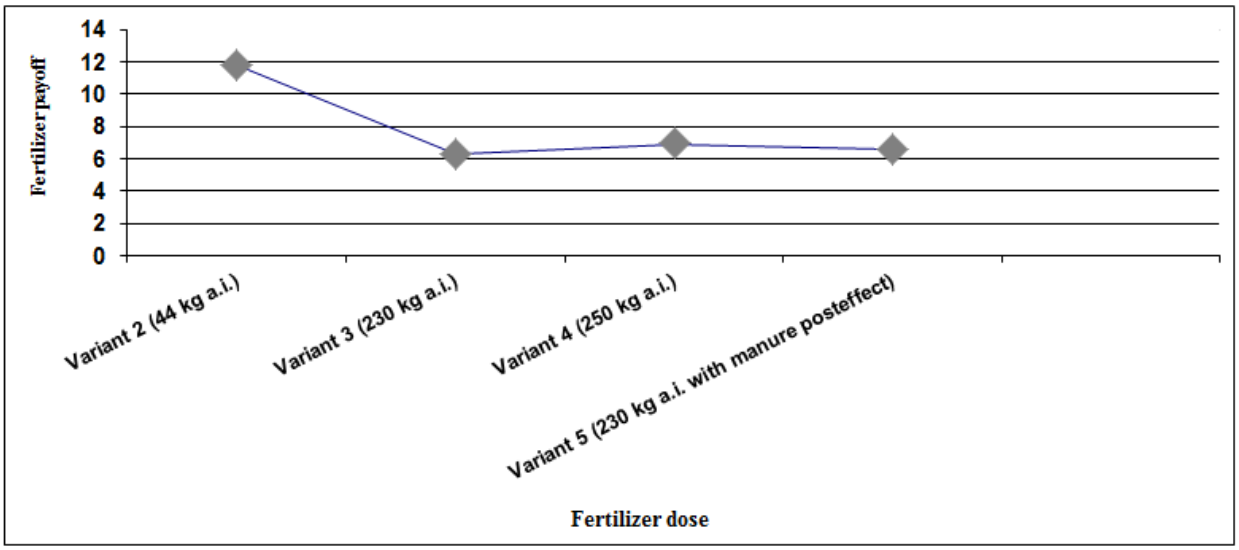

Fig. 4. Fertilizer payoff by the increase in the winter rye grain yield, average for the years of research, kg/kg a.i.

fertilizer, and significantly – at calculated doses of fertilizers. So, the application of $N_{12}P_{16}K_{16}$ (variant 2) ensured an increase in "raw" protein content by 0.4% in absolute units or by 3% in relative units compared to control, and application of $N_{90}P_{40}K_{100\text{-}120}$ (variants 3 to 5) – by 1.8–2.0% in absolute units or by 16–17% in relative units (Figure 3).

Payoff of fertilizers in the yield of winter rye grain was decreasing with increased doses of fertilizers and provided with the introduction of 44 kg a.i. fertilizers (variant 2) 11.8 kg of grain, and when applying 230 – 250 kg a.i./ha fertilizers – 6.3–6.9 kg/ha of grains. Organic-mineral fertilizer system had a slight advantage over the mineral one in payoff – by 0.3 kg of winter rye grain (figure 4).

4 Conclusion

Thus, on the sod-podzolic medium loamy soil of the Vologda region, applying calculated doses of fertilizers $N_{90}P_{40}K_{100\text{-}120}$ increases the yield of winter rye grains by 67–79% compared to control. When applying fertilizers in the amount of $N_{12}P_{16}K_{16}$, the yield of straw of winter rye increases by 25%. When applying full estimated doses of fertilizer $N_{90}P_{40}K_{100\text{-}120}$, straw yield increases by 74–87% compared to control. The uptake of nutrients by 1 ton of winter rye grain with the respective amount of straw when applying calculated doses of fertilizer compared to the control increases: for nitrogen – by 3 kg, for potassium – by 3 to 4 kg, and does not change for phosphorus. When applying $N_{12}P_{16}K_{16}$, the "raw" protein content is increased by 0.4% in absolute units or by 3% in relative units compared to control, and with $N_{90}P_{40}K_{100\text{-}120}$ – by 1.8–2.0% in absolute or by 16–17% in relative units.

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