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Influence of nitrogen fertilizers on protein productivity of vetch-wheat grain under different water supply conditions

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ABSTRACT

The peculiarity of nitrogen nutrition for legume-cereal mixtures is that due to the intravital transfer of mineral nutrition elements from the legume component of the mixture to the cereal component and vice versa, the cereal component receives nitrogen from the air symbiotically fixed by the legume component. This explains its better development in the mixture than in single-species sowing without the use of nitrogen fertilizers. In unfavorable conditions for legume-rhizobial symbiosis, when the assimilation of air nitrogen is weakened, and the legume and cereal components of the mixture are deficient in nitrogen, therefore, the issue of nitrogen fertilizer use expediency for legume-cereal mixtures is relevant. We have studied the effects of low and medium doses of nitrogen fertilizers including 30, 60 and 90 kg ha^{-1} (as treatments N_{30}, N_{60} and N_{90}) on the content and yield of crude protein with the grain yield of the vetch-wheat mixture under the conditions of sod-podzolic sandy loam soil in the central region of the Non-Chernozem zone with insufficient and optimal moisture. The protein content (% of dry matter) was determined by the calculation method according to the nitrogen content (N% × 6.25). On the control without nitrogen fertilizers, the protein content in vetch seeds and in wheat grain under the conditions of optimal moisture (2019) was higher than under the conditions of insufficient moisture (2018), by 0.4% and 0.3%, respectively. Nitrogen fertilizers increased the protein content in wheat grain by 0.2 - 0.4% during both years of study. The protein content in vetch seeds under the influence of nitrogen fertilizers increased only under the conditions of insufficient moisture by 0.2-0.7%. The protein yield with the wheat grain yield during both years of study upraised, as the dose of nitrogen fertilizers elevated by 1.6 - 2.7 times, and by the vetch harvest and insufficient moisture it remained unchanged, and by optimal moisture it droped by 13.7-34.7%. The protein yield with the grain yield of the mixture elevated by 44.4-91.1% under the influence of nitrogen fertilizers in arid conditions completely due to the wheat protein increase, while in conditions of sufficient moisture it droped by 5.2-17.8% due to the vetch protein decrease. Nitrogen fertilizers increased the competitiveness of wheat mixed with vetch under the conditions of insufficient moisture by 1.7-3.0 times, and under the conditions of optimal moisture by 1.9-4.1 times.

Key words: Vetch, Spring wheat, Protein yield, Competitiveness.
Article type: Research Article.

INTRODUCTION

Nitrogen is rightfully considered as the main factor in agricultural crop yield increase and in the protein content of crop product increase (FAO 2011; Leghari *et al.* 2016). The main nitrogen sources for most field crops are soil nitrogen and fertilizer nitrogen. The exception is legume plants, which fully meet their nitrogen requirements due to the symbiosis with nodule bacteria of the genus Rhizobium (Papastilianou & Danso 1989; Kretovich 1987; Jorrin & Imperial 2015). The most important advantage of symbiotic nitrogen is that it is completely assimilated

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by legumes, while the assimilation of mineral nitrogen introduced into the soil by plants is less than 60%, which leads to the pollution of groundwater and water bodies (Miao *et al.* 2011; Khan *et al*. 2018). Therefore, the increase of leguminous crop area has not only economic, but also ecological significance. Legume-cereal mixtures are widespread in agricultural production, along with single-species crops of leguminous varieties. Their role is especially great in fodder production. There are many reports about fertilizers and their importance in agriculture (Ashouri 2019; Vladimirovna Demina *et al.* 2020; Abolhasani *et al.* 2021; Omidipour *et al.* 2021). Nitrogen nutrition of legume-cereal mixtures has its own characteristics. It has been established that there is an in vivo transfer of mineral nutrition elements from the legume component of the mixture to the cereal one and vice versa (Wacquant *et al.* 1989; Morris *et al.* 1990; Neill & Wood 1990). Due to this, the cereal component of the mixture receives air nitrogen symbiotically fixed by the legume component, which ensures its better development than in single-species sowing without the use of nitrogen fertilizers. Therefore, the yield of legume-cereal mixtures increases in comparison with single-species crops of cereals (Oyun 2019; Volpe *et al.* 2017). However, under the conditions unfavorable for the legume-rhizobial symbiosis, when the assimilation of nitrogen in the air is weakened, and the legume and cereal components of the mixture are deficient in nitrogen, therefore, the issue of nitrogen fertilizer use expediency for legume-cereal mixtures is relevant.

MATERIALS AND METHODS

The aim of the study was to determine the effects of low and medium doses of nitrogen fertilizers on the yield of protein with the grain yield of the vetch-wheat mixture in the conditions of sod-podzolic sandy loam soil of the central region of the Non-Chernozem zone. The study was carried out on the experimental field of the Kaluga branch of the Russian State Agrarian University, Moscow Agricultural Academy named after KA Timiryazev in 2018 - 2019. The experiment scheme included 4 options: 1) N_0 (without fertilizers); 2) N_{30} (30 kg ha^{-1} N); 3) N_{60} (60 kg ha^{-1} N); 4) N_{90} (90 kg ha^{-1} N). The experiment was based on the method of randomized repetitions in 4 repetitions. The seeding rate of vetch sowing was 1.5 million units ha^{-1}, spring wheat 3.5 million units ha^{-1} of germinating seeds. Agrochemical characteristics of the arable soil layer: humus content 1.1-1.3% (according to Tyurin), mobile potassium and phosphorus 71-80 and 228-252 mg kg^{-1} of soil, respectively (according to Kirsanov), pH_{sol} 5.6 -5.8. To optimize potassium nutrition, potash fertilizers were applied as a general background at the dose of 60 kg ha^{-1} of K_2O. The protein content, expressed in % of dry matter, was determined by calculation according to the nitrogen content (N% × 6.25). The nitrogen content was determined by the Kjeldahl method. The studies used the generally accepted methods of field experiment conduct and evaluation of experimental data reliability (Novoselov 1987; Dospekhov 1985).

RESULTS AND DISCUSSION

The optimal level of moisture supply is one of the main factors in the active assimilation of air nitrogen by the vetch in symbiosis with nodule bacteria. The analysis of weather conditions shows that 2018 was dry, the amount of precipitation during the growing season was 67% of the climatic norm, and the average daily air temperature during the seed filling period was 2.9 ºC higher than the climatic norm. Sowing vetch is a moisture-loving culture, has an underdeveloped root system, and such climatic parameters are critical for it, even on sandy loam soil. In 2019, the temperature regime was at the level of the climatic norm, the amount of precipitation during the growing season was also at the level of the climatic norm, but their distribution was favorable for the vetch - most of them fell during the flowering period - the formation of beans. The study carried out show that under the conditions of optimal moisture (2019), the protein content is higher than in conditions of insufficient moisture (2018) by 0.4% and 0.3%, respectively, both for vetch and wheat seeds in the control without nitrogen fertilizers. This indicates a better supply of biological nitrogen to plants due to the symbiotic fixation of air nitrogen by the sowing vetch. This also indicates a better supply of biological nitrogen to plants due to the symbiotic fixation of air nitrogen with the sowing vetch. The effect of nitrogen fertilization on the protein content in vetch seeds also depended on the moisture conditions. By insufficient moisture, nitrogen fertilization had a positive effect on the protein content in vetch seeds. Depending on the dose of mineral nitrogen, it increased by 0.2- 0.7%. The greatest upraise in protein content was observed at the dose of mineral nitrogen of 90 kg ha^{-1} (N_{90}). By optimal moisture, nitrogen fertilizers in the studied doses did not affect the protein content in vetch seeds. The protein content in wheat grain, regardless of the moisture conditions, steadily increased in proportion to the dose of mineral nitrogen: at the dose of N_{30} by 0.1-0.3%, at N_{60} by 0.2-0.3%, and at N_{90} by 0.2-0,4%. The weighted average protein content in the

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grain of the mixture under the conditions of optimal moisture was 1.4 - 1.6 times higher than in insufficient moisture conditions. Nitrogen fertilizers led to the protein content decrease in the mixture grain. The more the decrease the higher the dose. At the same time, the sharpest drop was observed in the conditions of insufficient moisture. The protein yield with the grain yield of the vetch-wheat mixture was calculated on the basis of the yield data published by Khramoy *et al.* (2020). In 2018, under conditions of insufficient moisture, the yield of vetch seeds in mixed sowing using spring wheat was extremely low (0.18 - 0.21 ton ha^{-1}, respectively), likewise, the protein yield using the vetch crop was extremely low (40.4 - 46.4 kg ha^{-1}) and almost did not depend on nitrogen fertilizers. The wheat grain yield under these conditions was 2.1 - 7.2 times higher than the yield of vetch, varied from 0.43 ton ha^{-1} in the control to 1.3 ton ha^{-1} in the treatment of N_{90}. The protein yield with wheat yield elevated as the dose of mineral nitrogen upraised by 1.8-2.7 times (from 52.9 kg ha^{-1} in the control group to 144.2 kg ha^{-1} in N_{90}). The total yield of protein with the grain yield of the mixture in the treatment with nitrogen fertilizers also increased by 1.4-1.9 times (from 96.6 to 184.6 kg ha^{-1}). Under the conditions of optimal moisture (2019), vetch developed better in the control, its yield was 1.99 ton ha^{-1}. The application of nitrogen fertilizers led to vetch yield drop: at the doses of N_{30}, N_{60} and N_{90} reached up to 1.71, 1.43 and 1.30 ton ha^{-1} respectively. In proportion to the decrease of vetch yield under the influence of nitrogen fertilizers, the protein yield also dropped by 13.7 - 34.7%. Wheat without nitrogen fertilizers could not compete with vetch, and its yield in the control was only 0.30 ton ha^{-1}. Nitrogen fertilizers increased the competitiveness of wheat, its yield elevated to 0.51 - 0.84 ton ha^{-1}, likewise the protein yield by 1.6 - 2.7 times. However, this elevation could not compensate for the drop in the protein yield with the vetch crop, and the total protein yield with the mixture crop decreased by 5.2% under the influence of nitrogen fertilizers at the dose of N_{30} and N_{60} - by 14.4% and at N_{90} by 17.8%.

Table 1. Content and collection of protein with the grain yield of the vetch-wheat mixture, depending on the moisture conditions and the dose of nitrogen fertilizers.

Variant	Protein content (%)			Protein yield (kg ha^{-1})			Ratio
	vetch	wheat	mixture	vetch	wheat	mixture	vetch:wheat
2018 (insufficient moisturisation)							
Control	25.4	14.3	17.9	43.7	52.9	96.6	1.0 : 1.21
N_{30}	25.7	14.6	15.3	46.4	92.9	139.3	1.0 : 2.00
N_{60}	25.6	14.6	14.7	44.0	119.0	163.1	1.0 : 2.70
N_{90}	26.1	14.7	14.5	40.4	144.2	184.6	1.0 : 3.57
HCP_{05}				10.1	9.9	11.3	
2019 (optimal moisturisation)							
Control	25.8	14.6	24.3	441.5	38.8	480.3	1.0 : 0.09
N_{30}	25.8	14.7	23.8	380.9	64.6	455.3	1.0 : 0.17
N_{60}	25.9	14.8	22.0	317.3	93.9	411.2	1.0 : 0.30
N_{90}	25.8	14.8	21.5	288.4	106.6	395.0	1.0 : 0.37
HCP_{05}				50.4	10.2	43.4	
In two years on average							
Control	25.6	14.4	22.9	242.6	45.8	288.4	1.0 : 0.19
N_{30}	25.8	14.6	20.7	213.6	78.8	292.4	1.0 : 0.37
N_{60}	25.8	14.7	19.3	180.6	106.5	287.1	1.0 : 0.59
N_{90}	26.0	14.8	18.6	164.4	125.4	289.8	1.0 : 0.76

On average, in two years, the collection of protein with the vetch seed yield decreased by 12.0% at treatments of N_{30} and N_{60} by 25.6% and at N_{90} by 32.2%, while in the case of the wheat grain harvest, those elevated by 1.7, 2.3 and 2.7 times, respectively. However, the collection of protein according to the experiment tratments turned out to be at the same level, regardless of the level of mineral nitrogen nutrition. We used the ratio of vetch to wheat protein yield as the indicator of the mixture component competitiveness. Under conditions of insufficient moisture, the competitiveness of wheat increased, even without the use of nitrogen fertilizers. Wheat exceeded vetch in terms of protein yield by 1.2 times. Under the conditions of optimal moisture, the competitiveness of vetch sharply elevated; vetch in the control exceeded wheat in protein yield by 11.4 times. Nitrogen fertilizers increased the competitiveness of wheat by 1.7 - 3.0 times in conditions of insufficient moisture, while by 1.9 - 4.1 times in conditions of optimal moisture.

CONCLUSION

The studies have shown that the use of nitrogen fertilizers at the doses of 30, 60 and 90 kg ha^{-1} under the vetch-wheat mixture provides the protein yield increase with the grain yield of the mixture only under the conditions of

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insufficient moisture, when the development of the vetch is weakened, and the yield of the mixture is formed mainly due to wheat. So, it is possible to recommend abandoning the pre-sowing application of nitrogen fertilizers under the vetch-wheat mixture and applying fertilizers with mineral nitrogen at the beginning of the growing season, based on the analysis of the moisture conditions and the crop state.

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