Effect of mineral fertilizers on productivity and quality of yellow lupine cultivated on soddy-podzolic sandy soil

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Abstract. The article presents the results of investigations carried out in a field experiment on sod-podzolic sandy soil contaminated with radionuclides, the efficiency of influence of doses and kinds of potassium fertilizers on the yield, 137Cs accumulation and fodder value of yellow lupine was studied. The carried out researches showed that the optimum doses of phosphorus-potassium fertilizers for getting an increased yield of green mass is P45K150, in both studied types of potassium fertilizers. To get the maximum grain yield of lupine, the optimal doses of mineral fertilizers are P45K150 and P45K210. Analyzing the effect of different types of potassium fertilizers on the formation of yellow lupine grain yield, it can be noted that the use of potassium fertilizer - Kalimag, the yield was higher than that of potassium chloride. To decrease accumulation of 137Cs in lupine green mass below permissible level, the doses of mineral fertilizers shouldn't be less than P45K150. Maximum decrease of radionuclides in the grain was noted in the variant P45K210 (Kmg).

Keywords: yellow lupine, phosphorus and potassium fertilizers, potash - Kmg, potassium chloride - Kcl, yield, quality, accumulation, 137Cs.

1. Introduction

The importance of lupine in modern agriculture is objectively increasing; its high biological and economic potential makes it possible to grow and use it in many regions of Russia [1,2]. The main advantage of lupine is its biological ability to grow and develop well on very poor sandy soils [3]. Lupine is an important legume crop on soddy-podzolic sandy soils of light mechanical composition. Lupine green mass and stubble-root residues are an important factor of biological farming, energy and resource saving [4].

Lupine is a valuable legume crop used for green fodder, silage, grain forage and as a siderat. Lupine is an indispensable ingredient for balanced feed [5-7].

Protein content in feeds is one of the most important and significant indicators of quality. Lupine is one of the main sources of protein supplementation in feeds. Using lupine for fodder enriches the ration, protects farms from irrational use of feed and reduces the cost of milk and meat production. Lupine grain is regarded as a source of balanced, easily digestible and environmentally friendly protein in the diet of feeding all types of animals [8,9]. At the same time, the increased accumulation of 137Cs in the radionuclide-contaminated soils of the Bryansk region limits its application. The reduction of radionuclide accumulation in plants is the most important task. The system of fertilizer application...
significantly affects the radionuclides ingress to the plants and their accumulation in the crop. Therefore, the use of fertilizers should help to reduce the intake of radionuclides into plants [10,11].

The aim of our research was to study the influence of mineral fertilizers on productivity, quality and fodder value of yellow lupine cultivated on soddy-podzolic sandy soil contaminated with radionuclides.

2. Objects and methods
The studies were performed in 2015 - 2017 on the experimental field of Novozybkovskaya agricultural experimental station, on soddy-podzolic sandy soil contaminated with radionuclides. Bookmarking, field experiments, statistical data processing, and laboratory-analytical works were performed according to the methods [12-15]. Lupine yellow variety Novozybkovsky 100 was the research object.

The soil of the experimental plot was soddy-podzolic sandy. Arable horizon thickness is 20-22 cm. Agrochemical indicators of soil fertility of arable layer before the experiment: humus (by Tyurin) - 1.6%, pHx1 - 4.87; hydrolytic acidity (by Kappen-Hilkovitz) - 2.41 mg-eq./100 g.p. total exchangeable bases (by Kappen-Hilkovitz) - 2.59 eq./100 gp; content of mobile forms of phosphorus (by Kirsanov) - 32.1 mg/100 g of soil, content of mobile forms of potassium (by Kirsanov) - 11.1 mg/100 g of soil.

The specific activity of the soil of the experimental plot 1937 is 2131 Bq/kg, the density of 137Cs contamination of the soil as a result of the Chernobyl disaster is 562 - 618 kBq/m2.

Mineral fertilizers: simple granulated superphosphate (P-22%), potassium chloride (K-56%) and Kalimag (K-35%) were applied under lupine in spring under cultivation. The experiment was conducted in 3-fold replication, the total area of experimental plot 36 m2, accounting 30 m2. Cultivation technology of lupine is generally accepted, recommended for the zone.

The experiment includes the following variants: 1. Control, 2. P45, 3. P45K90 (Kcl), 4. P45K150 (Kcl), 5. P45K210 (Cl), 6. P45K90 (Kmg), 7. P45K150 (Kmg), 8. P45K210 (Kmg).

3. Research results
Weather conditions in the years of research differed significantly in moisture and heat supply. Thus, 2017 was dry and was characterized by a low reserve of productive moisture in the soil, uneven distribution of spring-summer precipitation and high air temperature in the first half of the growing season. Therefore, the yield of yellow lupine fluctuated by years of research.

According to the results of the studies we can note that the yield of green mass of yellow lupine (on average for 3 years) in the control variant, without the application of mineral fertilizers, was 32.3 t/ha (Table 1). In the variant of application of phosphorus fertilizer at the dose of 45 kg/ha the tendency to increase of lupine green mass yield was noted.

The use of different types of potassium fertilizers (potassium chloride and Kalimag) at a dose of K90, in addition to P45, slightly increased green mass yield. Potassium at a dose of 150 kg/ha (in both types of potassium fertilizer studied) significantly increased green matter yields by 19 and 24%. Increasing the doses of potassium fertilizers to 210 kg/ha gave a steady tendency to increase the yield (compared with a dose of 150 kg/ha), in relation to the control variant, the collection of green mass of lupine increased by 29 and 32%.

It follows that according to the results of our experiment, the optimal dose of mineral fertilizer to get the maximum yield of green mass of yellow lupine - P45K150 (regardless of the type of potassium fertilizer), the subsequent increase in dose of potassium fertilizer did not have a significant impact on green mass yield. At all doses of potassium fertilizer in the form of Kalimag, there was a stable tendency to increase the green mass yield of lupine, compared with the same doses of another type of potassium fertilizer (KCl).
Table 1. Effect of mineral fertilizers on the yield of green mass and grain of yellow lupine, variety Novozybkovsky 100, (average for the years of research).

| Variant          | Green mass |          | Grain |          |
|------------------|------------|----------|-------|----------|
|                  | Yield, t/ha| increment, t/ha | Yield, t/ha | increment, t/ha |
|                  |            | total | from potassium |            | total | from potassium |
| Control          | 32,3       | 1,16   | 1,16 | 0,10    | 0,10 |
| P45              | 34,1       | 1,8    | 1,26 | 0,26    | 0,16 |
| P45K90(Kcl)      | 36,3       | 4,0    | 2,2  | 1,42    | 0,26 | 0,16 |
| P45K150(Kcl)     | 38,3       | 6,0    | 4,2  | 1,51    | 0,35 | 0,25 |
| P45K210(Kcl)     | 41,7       | 9,4    | 7,6  | 1,67    | 0,51 | 0,40 |
| P45K90(Kmg)      | 36,5       | 4,2    | 2,4  | 1,47    | 0,31 | 0,21 |
| P45K210(Kmg)     | 40,0       | 7,7    | 5,9  | 1,65    | 0,49 | 0,39 |
| P90K150(Kmg)     | 42,7       | 10,4   | 8,6  | 1,73    | 0,57 | 0,47 |
| HCP05, т/га      | 3,6        | 0,08   | 0,08 | 0,08    | 0,08 |
| P, %             | 3,1        | 1,7    | 1,7  | 1,7     | 1,7  |

Lupine grain yield, on average over the years of research, on the absolute control was 1.16 t/ha (Table 1), phosphate fertilizers, applied at a dose of 45 kg/ha, increased grain yield by 9%. Potassium fertilizer (in both studied types) in the minimum dose - 90 kg/ha, applied in combination with phosphorus fertilizer (P45), increased grain yield by 14 and 18%, no significant difference between the studied types of fertilizer. The application of potassium fertilizer in the form of potassium chloride at a dose of 150 kg/ha increased grain yield by 22%, the floor dose of Kalimag increased grain yield by 34%, which is significantly higher than the application of potassium chloride. The maximum grain yield was on the variant P45K210 (in both studied species), the grain gains were 0.51 and 0.57 t/ha. From the application of potassium fertilizer in the form of kalimag, as in the green mass, there was a steady tendency to increase grain yield in relation to the variants, where potassium chloride was used.

Analyzing our research, it can be noted that the studied two types of potassium fertilizers increased the grain yield of yellow lupine: at the minimum dose almost equally, at the average dose (K150) Kalimag increased the grain yield significantly higher. The maximum yield was obtained on the variants with higher doses of potassium fertilizer, regardless of the type of potassium fertilizer.

The main indicators of fodder value for lupine are the content of protein and alkaloids. The content of protein in green mass on the control is 17,83% (table 2), in variants of application of mineral fertilizers the content of protein has increased to 19,43%, the maximum content on the variants with the use of potassium fertilizer in the form of Kalimag in combination with phosphorus fertilizer.

The content of crude protein in the grain of yellow lupine in the control variant - 43,38%, due to the use of mineral fertilizers can be traced reduction of protein content in all variants of fertilizers.

The content of alkaloids in the green mass on the control 0,013%, from the application of mineral fertilizers significant changes in the content of alkaloids was not observed.

The content of alkaloids in yellow lupine grain varied by the experimental variants from 0,057% to 0,065%, which refers to low content of alkaloids (0,025-0,099%) [16].

An important quality indicator of agricultural crops in the radioactive contamination zone is the 137Cs content in the final products of crop production complying with requirements of WP - 13.5.13./06 - 01 - for green mass 100 Bq/kg, 137Cs MPL - for grain 180 Bq/kg, TRTS 015 / 2011 of December 9 11, № 874.

The 137Cs content in green mass of lupine in the control variant was 2 times higher than normatively permitted level (Table 2). The increase of accumulation of radionuclides by 9% was observed in the variant of phosphorous fertilizers. Application of potassium fertilizer, together with phosphorus fertilizer, at a dose of 90 kg/ha (in both studied potassium fertilizers) reduced radiocaesium
accumulation, but its amount also exceeded the permissible level. Phosphorus-potassium fertilizers with potassium doses of 150 and 210 kg/ha reduced the accumulation of $^{137}$Cs in green matter below the standard allowable level, it follows that green matter can be used for feeding animals without restrictions.

Analyzing the results of our research, it can be noted that to obtain the green mass of lupine corresponding to the normative requirements for the content of radionuclides, it is necessary to make mineral fertilizers in a dose not less than P$_{45}$K$_{150}$.

Table 2. Effect of mineral fertilizers on the quality of green mass and grain of yellow lupine, variety Novozybkovsky 100, (the average for the years of research).

| Variant          | Green mass content (%) per abs. dry matter | Grain content of $^{137}$Cs, Bq/kg | Content (%) per abs. dry matter | Grain content of $^{137}$Cs, Bq/kg |
|------------------|------------------------------------------|-----------------------------------|---------------------------------|-----------------------------------|
|                  | crude protein                           | alkaloids                          | Bq/kg                           | crude protein | alkaloids | Bq/kg                           |
| Control          | 17.83                                    | 0.013                              | 198                             | 43.38          | 0.059     | 694                             |
| P$_{45}$         | 18.76                                    | 0.014                              | 216                             | 41.85          | 0.062     | 740                             |
| P$_{45}$K$_{90}$ (Kcl) | 18.48                                   | 0.015                              | 109                             | 42.27          | 0.064     | 544                             |
| P$_{45}$K$_{150}$ (Kcl) | 19.13                                   | 0.014                              | 77                              | 41.86          | 0.065     | 488                             |
| P$_{45}$K$_{210}$ (Kcl) | 19.18                                   | 0.014                              | 66                              | 43.04          | 0.063     | 414                             |
| P$_{45}$K$_{90}$ (Kmg) | 19.43                                   | 0.014                              | 105                             | 42.60          | 0.061     | 498                             |
| P$_{45}$K$_{150}$ (Kmg) | 18.88                                   | 0.014                              | 70                              | 42.28          | 0.057     | 440                             |
| P$_{45}$K$_{210}$ (Kmg) | 18.43                                   | 0.014                              | 63                              | 42.46          | 0.064     | 358                             |

Specific activity of cesium in lupine grain, in the variant without fertilizers, in 3.8 times exceeds the normative allowable level. Phosphorus fertilizer used in the experiment scheme increased radionuclide accumulation. Potassium fertilizers studied in the experimental variants decreased the $^{137}$Cs content. Maximum decrease up to 358 Bq/kg was in the variant with application of potassium fertilizer - Kalimag in an increased dose which also exceeded the maximum permissible concentration of radionuclides in lupine grain but grain can be used as high-protein additive from other crops whose specific activity of $^{137}$Cs is low.

Fodder value of green mass and yellow lupine grain is presented in Table 3. The collection of fodder units from one hectare in the green mass of yellow lupine in the control variant was 2.55 t/ha, the maximum collection of fodder units was in the variant P$_{45}$K$_{210}$ (Kmg), from application of both types of potassium fertilizers, the gain was 0.77 and 0.87 t/ha.

The yield of fodder units with grain lupine in the control variant 1.35 t/ha, through the use of mineral fertilizers increased grain yield respectively increased and the collection of fodder units, the maximum in the variant P$_{45}$K$_{210}$ (Kmg) at 0.64 t/ha.

Collection of digestible protein in green mass from 1 ha in the variant without fertilizers - 0.68 t/ha. Mineral fertilizers (phosphorus-potassium) increased the yield of green mass of lupine and the content of crude protein in it, and accordingly increased the collection of protein by 0.25 t/ha (variant with higher doses of mineral fertilizers).

Collection of digestible protein in lupine grain per hectare on the control - 0.41 t, mineral fertilizers used on the variants of experience increased its collection, the maximum collection of digestible protein was on the variants P$_{45}$K$_{210}$ (Kmg) - 0.60 t/ha.
Table 3. Fodder value of green mass and grain of yellow lupine, variety Novozybkovsky 100, (average for the years of research).

| Variant            | Green mass |           |           | Grain |           |           |
|--------------------|------------|-----------|-----------|-------|-----------|-----------|
|                    | digestible | fodder    | metabolizable | digestible | fodder    | metabolizable |
|                    | protein    | unit output | energy, (GJ / | protein | unit output | energy, (GJ / |
|                    | output (t/ha)| (t/ha)    | ha)       | output (t/ha)| (t/ha)    | ha)       |
| Control            | 0,68       | 2,55      | 40,52     | 0,41   | 1,35      | 13,98     |
| P45                | 0,78       | 2,83      | 43,89     | 0,43   | 1,43      | 15,04     |
| P45K90 (Kcl)       | 0,78       | 3,00      | 46,08     | 0,49   | 1,63      | 17,04     |
| P45K150 (Kcl)      | 0,86       | 3,10      | 48,07     | 0,51   | 1,69      | 17,86     |
| P45K210 (Kcl)      | 0,93       | 3,32      | 51,70     | 0,58   | 1,92      | 20,04     |
| P45K90 (Kmg)       | 0,84       | 2,99      | 46,23     | 0,52   | 1,69      | 17,63     |
| P45K150 (Kmg)      | 0,86       | 3,06      | 48,58     | 0,56   | 1,93      | 19,93     |
| P45K210 (Kmg)      | 0,90       | 3,42      | 52,97     | 0,60   | 1,99      | 20,74     |

Based on the experimental data it can be noted that the metabolizable energy in the green mass of yellow lupine increased on the experimental variants from 40.52 to 52.97 GJ.

The metabolizable energy in the grain of yellow lupine, due to the use of mineral fertilizers on the experimental variants increased by 6.76 GJ.

4. Conclusion
Thus, based on the experimental data we may say that for getting the maximum yield of the green mass of yellow lupine the optimal doses of mineral fertilizers are P45K150 (irrespective of the kind of potassium fertilizer). In variants potassium fertilizer in the form of Kalimag there was a strong tendency to increase the harvest of green mass.

To obtain an increased yield of lupine grain it is necessary to make fertilizers in doses P45K150 or P45K210. The effect of the two studied types of potassium fertilizers on productivity was not the same, so on the variants of application of potassium fertilizer in the form of Kalimag grain yield was higher than on the variants of application of potassium chloride.

In the result of researches it has been established that the green mass of yellow lupine with the content of radionuclides below normatively admissible level was received at the variants of mineral fertilizer - P45K150 and higher. In our researches the minimal content of radionuclides in lupine grain was at the variant - P45K210(Kmg), which also exceeded twice the maximum permissible concentration of radionuclides. The grain can be used as a high-protein additive to crops with low 137Cs content.

References
[1] Likhachev B.S. 1996 Strategy and priorities in lupine breeding Thesis of the IV International Scientific Conference "Biological nitrogen in crop production". SOISAF. Moscow, P. 121-123
[2] Ageeva P A 1997 Selection of narrow-leaved lupine and creation of a new generation of agroecotypes varieties. Scientific basis for creating models of agroecotypes of varieties and zonal technologies of cultivation of grain legumes and cereal crops for different regions of Russia. Orel P. 110-114
[3] Takunov I.P. 1996 Lupin in agriculture of Russia Monograph Bryansk Pridesenje 372 p.
[4] Takunov I.P 2001 Energy-saving role of lupine in modern agricultural production. 3-4
[5] Savvicheva I K, Likhachev B S 2012 Selection of yellow lupine in Bryanskchina Jl Feed Production No 5 P. 29-31
[6] Yagovenko G.L., Belous N.M., Yagovenko L.L. 2011 Lupine in agriculture of the central region of Russia: influence on agrochemical properties of grey forest soil and productivity of crop rotations Monograph Bryansk 182 p.
[7] Belous N M, Torikov V E, Moiseenko I Ya, Melnikova O V 2010 Grain legumes and annual leguminous grasses: biology and technology of cultivation Bryansk 151 p

[8] I.P. Takunov, T.N. Slesareva 2007 Herbicide-free resource-saving technology of lupine and cereal crops cultivation in mixed crops. Scientific and practical guide Bryansk "Chitay-gorod" 60 p.

[9] Privalov F I, Shor V C 2015 Prospects of cultivation, breeding and seed production of lupine in Belarus JL Vesci natsional'nyi akademi nauk Belarusi No. 2 P. 47-53

[10] Korenev V B, Vorobieva L A, Belous I N 2013 Yield of forage and grain crops, and 137Cs accumulation depending on the introduction of increasing doses of potassium fertilizers Bulletin of the Bryansk State Agricultural Academy № 5 P. 3-6

[11] Sychev V G, Lunev V I, Orlov P M, Belous N M 2016 Chernobyl: radiation monitoring of agricultural land and agrochemical aspects of reducing the consequences of radioactive soil contamination (to the 30th anniversary of the man-made accident at the Chernobyl NPP) Collection of articles Moscow VNIIA, 184 p.

[12] Dospekhov B.A. 1985 Methodology of field experiment (with statistical processing of research results) Moscow Agropromizdat 351 p.

[13] Methodical instructions for research in long-term experiments with fertilizers. 1975 p 1 Moscow WIUA p 167, 1983 p 2 Moscow WIUA p 161, 1985 p 3 Moscow WIUA 131 p

[14] Methodic instructions for determination of natural radionuclides in soil and plants 1985 Moscow CINAO 22 p

[15] Artyukhov A I, Yagovenko T V, Afonina E V, Troshina L V 2012 Methodical recommendations "Quantitative determination of alkaloids in lupine (Bryansk: "Chitay-gorod") 16 p

[16] Kuptsov N S, Takunov I P 2006 Lupin - genetics, breeding, heterogeneous crops Bryansk 576 p