Optimization of plant nutrition using non-traditional organic fertilizers and zeolite-containing tripoli

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Abstract. The problem of conservation and reproduction of soil fertility by using unconventional organic fertilizers, particularly the replacement of the mineral nitrogen fertilizer to its organic form is discussed. The growth of the livestock industry lays the groundwork for the recovery of meat processing industry waste of horned ungulate crumbs (HAC) as fertilizer for inter-tilled crops. HAC contains about 14% nitrogen. Experiments on the application of HAC as a nitrogen fertilizer and sorption-type ameliorant – zeolite-containing tripoli were organized in 2012-2016 in the crop rotation link on the light gray forest soil of the experimental field of the FSBEI HE Chuvash State Agricultural Academy, Chuvash Republic. In this paper, the effect of the HAC-form on the optimization of nitrogen nutrition of the studied crops both separately and for tripoli having phosphorus-potassium mineral fertilizers is studied. The positive effect of HAC and tripoli on the growth and development of potato and fodder beet plants, soil biological activity, leaf surface area, yield and quality indicators of potato tubers and fodder beet root crops both in the first year when fertilizers are applied and in their aftereffect in the second year for barley yield was revealed. The study materials contribute to the practical solution of the problem of the recovery of meat processing industry waste and rational use of resources in the fertilizer system, being a guide to energy and resource conservation in agriculture.

1. Introduction

Based on the research project “Agricultural Market Survey-2018”, conducted by Deloitte Russia, a steady growth in production is observed, both in the livestock sector and in crop production, and there are forecasts that this trend will continue in the country due to a reform in subsidizing loans and state investment in agricultural enterprises [1].

In this regard, farmers shall pay special attention to soil fertility in the fertilizer system for the planned crop production [2].

Nitrogen fertilizers play a key role in the accumulation of plant mass of cultivated agricultural plants. In turn, by leaving a large number of root and stubble residues in the soil, plants participate in enriching the soil with organic matter, improving its water and physical properties. It is well known that when nitrogen fertilizers are applied per year, nitrogen losses constitute 15-30% due to denitrification, 25-35 % of nitrogen is absorbed by soil microorganisms, about 5-15% is lost due to
leaching by precipitation. It follows that the plant receives less than half the dose of the applied nitrogen fertilizers.

Biele P. (1984) notes that mineral nitrogen fertilizers have virtually no aftereffect. He also points out that mineral nitrogen is immobilized much faster under aerobic conditions than under conditions without oxygen [3].

Vasiliev O. (2008, 2015) and Shashkarov L. (2017) note that the easiest way to reduce nitrogen losses of fertilizers is fractional application of a nitrogen dose from planting (sowing) during the accumulation of vegetative mass of plants to the formation of reproductive organs, which increases the efficiency of its use by the plant. However, in practice, this situation is very difficult to achieve due to agro-technical and organizational & economic reasons [4].

At present, with the development of the agricultural industry, the problem of nitrates in foodstuffs concerns not only physicians, but also more and more often attracts the attention of specialists, agricultural workers and the public. The large number of publications on this issue confirms this [5].

However, nitrates are a source of plant nutrition, since nitrogen, which is a part of them, is the main biogenic element [6]. Nitrates in a plant accumulate only if the absorbed nitrogen is used only partially in the synthesis of amino acids, and then proteins, i.e., in the process of metabolism in the plant, not all absorbed nitrates are reduced to ammonia [7]. However, at the present stage of development of agricultural production, the problem of waste disposal is quite urgent, because when they accumulate in large quantities at production sites without disposal, they are a source of environmental pollution, and worsen the sanitary, epidemiological and aesthetic qualities of the natural surroundings.

Unlike mineral fertilizers, which have a high solubility, organic fertilizer in the soil decomposes gradually under the action of soil microorganisms, and the nitrogen released is almost completely used by plants; being involved in the biological cycle, it is not washed out of the soil by atmospheric precipitation and does not evaporate into the atmosphere [8]. It is significant that in addition to being a source of nutrients for plants, organic fertilizer application facilitates waste recovery from crop production, animal husbandry and their processing, which can be attributed to resource saving [9].

In this regard, the application of unconventional organic fertilizers as a fertilizer (horned ungulate crumbs, bone meal, urban wastewater sludge, biogas plant waste from crop product processing, etc.), as a source of nitrogen nutrition elements during crop cultivation is relevant. Several researchers, including Vasiliev O. (2015) and Shashkarov L. et al. (2017, 2019), note that among the listed forms, the waste of the meat processing industry – horned ungulate crumbs both independently and together with zeolite-containing tripoli as a sorption-type soil enricher in the crop rotation link with tilled crops is of particular interest as an organic fertilizer.

The purpose of this study is scientific justification and development of methods for the effective use of meat processing industry waste – horned ungulate crumbs as an organic nitrogen fertilizer together with phosphorus-potassium mineral fertilizers, and zeolite-containing tripoli for potatoes and fodder beets, as well as their aftereffect on barley to obtain high, stable yields of good quality crops in the crop rotation link on gray forest soil in the Volga-Vyatka region.

2. Material and methods

In the early 2000s, we conducted a research at the Department of General Agriculture to study the effectiveness of horned ungulate crumbs or HAC (horned ungulate meal, or as formerly designated – HAM) as an organic fertilizer. In 2012-2015, the Department of Agriculture, Crop Farming, Breeding and Seed Production, FSBEI HE Chuvash State Agricultural Academy, conducted a study on fertilizers both in direct action on potatoes and feed beets and in the aftereffect on barley in 2013-2016.

The experimental field soil was light gray forest heavy loam in granulometric composition, with a low humus content of about 2.5 %. The amount of the absorbed bases was 18.6 m. – eq./100g of soil; soil environment reaction – close to neutral pH(KCl) 5.8 and 6.1. The arable layer is characterized by an increased content of mobile phosphorus (152 mg/kg) and a high content of exchange potassium (173 mg/kg). Ball bonitet – 68.9.
The research was carried out in the tilled grain crop rotation link: winter grains (winter wheat) - tilled crops (potatoes, fodder beets) - spring grains (barley). Experiment variants: 1) Control (without fertilizers); 2) Mineral fertilizers (N, P, K at 60 kg a.r./ha); 3) HAC (N 60 kg a.r./ha) + (P, K at 60 kg a.r./ha); 4) Mineral fertilizers (N, P, K at 60 kg a.r./ha) + tripoli (2 t/ha); 5) HAC (N 60 kg a.r./ha) + (P, K at 60 kg a.r./ha) + tripoli (2 t/ha), where: mineral fertilizer: N (nitrogen) - ammonium nitrate; P (phosphoric) - double superphosphate; K (potash) - potassium chloride.

Plot area – 56 m²; declared plot – 33.6 m²; replications – four. Placement is randomized. Total area of cultivated crops in the experiment – 2240 m². Declared plot area – 1344 m².

Analysis of weather conditions at the experimental site over the research years given in table 1 did not reveal significant deviations from the long-term average values for the agro-climatic zone conditions. They were characterized by quite satisfactory values for the amount of heat and moisture supply during the periods of growth and development of cultivated crops, see table 1.

Table 1. Moisture and heat supply conditions of the vegetation period over the research years.

| Years | 2012 | 2013 | 2014 | 2015 | 2016 | Long-time annual average |
|-------|------|------|------|------|------|--------------------------|
| HTC*  | 1.62 | 1.56 | 1.10 | 1.52 | 1.17 | 1.34                     |

*HTC – Hydrothermal coefficient.

Experimental crops and varieties that are the objects of the study: Beetroot – Ekkendorfsky grade, yellow. Potatoes – Nevsky grade. Barley – Elf grade [4].

Tripoli used in the experiment is a sedimentary finely porous rock that differs from diatomite by an admixture of clay and sand particles, a low content of organic residues and consists of small rounded opal particles with an admixture of clay mineral, quartz, glauconite and feldspar [10]. Tripoli has a Ca content of up to 15%, Mg up to 1.5%, K oxide up to 0.19%, P oxide and trace elements – 0.0001%, primarily Cu (up to 500 mg/kg), Mn (up to 550 mg/kg), Zn (up to 20 mg/kg), in significantly small quantities – B, Mo and Co (up to 3-5 mg/kg) and up to 14% zeolite content. The latter are frame aluminosilicates capable of exchanging ions and molecules with the soil solution [11].

Tripoli possesses good recovery properties for soils with low natural fertility: increases absorption capacity, degree of saturation with bases, reduces hydrolytic and metabolic acidity. Its properties as an adsorbent and an ion exchanger reduce the mobility of heavy metals and the intensity of their entry into plants [12], table 2.

Table 2. Chemical composition of tripoli.

| Sample | Content, % |
|--------|------------|
|        | SiO₂       | R₂O₃      | Fe₂O₃ | CaO | MgO | Loss on ignition |
| Tripoli| 73.4       | 4.5       | 2.6   | 7.9 | 1.1 | 10.5             |
|        | Cu         | B         | F     | P₂O₅| K₂O | SO₃             |
|        | 0.045      | 0.0075    | 0.009 | 0.64 | 0.02 | 0.1             |

The properties of the zeolite-bearing rocks of Chuvashia found across the southeastern part of the Alatyr Region have been known since the early 1930s. An area of about 17.5 ha on the Pervomaiskiy field holds up to 3 million tons of tripoli reserves. Analyzes for heavy metals and radionuclides have shown that Pervomaiskiytripoli is ecologically safe.

The use of horned ungulate crumbs (HAC) as an organic fertilizer, a product obtained by mechanical grinding of horns and hooves of farm animals, performs the function of environmental waste recovery. Statistics for Russia show that only in 2017, the potential resource of horns and hooves for horned stock was over 16.3 thousand tons. HAC is a loose product that is characterized by shades from gray to dark brown, has a specific (horney) smell. Contains macro- and micro-elements;
has a nitrogen content of 14%, due to the insignificant phosphorus content of up to 1% and 0.6% of potassium, in comparison with the nitrogen content, HAC is a nitrogen fertilizer.

The research methodology included analysis of soil samples at the Chuvash Federal State Budgetary Institution, State Center for Agrochemical Service, for the content of mobile phosphorus as per the Kirsanov method in the TsINAO modification on FEK-1; exchange potassium as per the Kirsanov method – GOST 26207-91; pH (KCl) of salt extract by potentiometric method as per GOST 26487-85; humus content as per Tyurin – GOST 26213-91; amount of absorbed bases as per Kappen, the soil nitrate content is ionometrically modified by TsINAO. Evaluation and accounting of the crop was carried out as per the methodological guidelines using the method of Dospekhov B.A., (2012). During the growing season, the following activities were conducted as part of the research: phenological observations of plant growth and development, study of growth dynamics, yield accounting etc. The studies were carried out as per the Gossortseti method (1971) and based on the recommendations of the FWRC FPA (previously, the All-Russian Williams Fodder Research Institute) (1987), as well as observing the weather conditions of the growing season. When accounting for the potato crop and its structure, the marketability and quality of tubers, as well as starch content (by specific gravity) were determined. When accounting for the harvest of root crops of fodder beets, the following qualitative indicators were determined: dry matter – by the gravimetric method, sugar – by the polarimetric method; nitrate content – by the ionometric method – GOST 29270-95 – “Fruit and Vegetable Processing Products. Nitrate Determination Methods”. The biological activity of the soil was determined by the application method as per the degree of decomposition of the bed. The leaf surface area on potatoes was determined by die cutting. The leaf area of the fodder beets was determined by measuring the leaf length and width of the leaf plate, multiplied by a factor of 0.84 for the Ekkendorf yellow variety. Statistical processing of experimental data was performed by the deviation analysis method of Dospekhov B.A. (2012). Soil bonitization by the Fatyanov A.S. method was the basis for choosing the fertilizer application rate in the experiment. Economic efficiency was calculated as per process flow diagrams, based on a system of in-kind and cost indicators, and using standards and prices adopted for the production conditions of the Chuvash Republic using computer technology. Energy assessment conducted as per the methodology of the Russian State Autonomous University, K.A. Timiryazev Moscow Agricultural Academy, 2007. Agricultural technology for the cultivation of potatoes, fodder beets and grain crops was generally accepted for the conditions of the Chuvash Republic.

3. Research results

It was revealed that weather conditions over the research years had an impact on the onset and duration of the phases of growth and development of potato plants. In particular, adverse weather conditions during critical periods of 2014 increased the interphase period by 1-3 days on potato plantings.

Over the years of studying the effect of fertilizers, an early onset of the flowering phase was revealed for 1-2 days in the variant with HAC addition, moreover, green leaves were more intense in color compared to the variants where the mineral nitrogen fertilizer was applied.

When determining the area of the assimilation surface of potato plants, it should be noted that over the research years in all cases, fertilization contributed to an increase in the area of the leaf surface of potato plants by 7.0-15.1 thousand m²/ha. Variants with the organic form of the nitrogen fertilizer-HAC had a significant excess of the leaf surface area of variants with the mineral nitrogen fertilizer on average for three years by 7.3 and 6.8 thousand m²/ha.

Observations of the dynamics of increase in leaf surface area on fodder beet crops showed that variants with the application of an organic nitrogen fertilizer together with phosphorus-potassium mineral fertilizers in a tripoli environment had the largest leaf surface area – 8.8 m²/ha and the variant with a mineral nitrogen fertilizer together with phosphorus and potassium mineral fertilizers and tripoli – 8.3 m²/ha.
The largest number of fodder beet leaves at the end of the growing season was observed in the variants where HAC was introduced as a nitrogen fertilizer, figure 1.

![Figure 1. Dynamics of the formation of fodder beet leaves, pieces per plant.](image1)

Based on the intensity of growth of fodder beet leaves, the mineral nitrogen fertilizer was effective only in the initial period, from which the assumption about the gradual release of nitrogen from the organic fertilizer HAC and the positive sorption properties of zeolite-containing tripoli can be made.

Based on the results obtained, it can be concluded that the organic form of the HAC nitrogen fertilizer introduced on tilled crops have a positive effect on the formation of their leaf apparatus.

The greatest activity of soil microflora in the field conditions on potato plantings by the rate of decomposition of flaxen linen was revealed in the variant with the application of organic nitrogen fertilizer as compared with the mineral nitrogen fertilizer more by 5.8%, and in similar versions against tripoli it increased by 8.5%, figure 2.

![Figure 2. Biological activity of soil under the potatoes on average over the research years, %](image2)

Moreover, on fodder beet crops in similar variants, the excess was 13.5% and 8.5%, respectively, compared with the control variant.

Accounting for the potato harvest revealed that the application of fertilizers and zeolite-containing tripoli has a significant increase compared to the control variant.
Moreover, the application of mineral and organic nitrogen fertilizers together with phosphorus-potassium fertilizers did not reveal significant differences between the variants in contrast to the variants in a tripoli environment, where a significant increase was observed. Evaluation of fodder beet yield and potatoes revealed that all variants with the application of fertilizers and zeolite-containing tripoli have a significant difference compared to the control.

Analysis of the potato yield over the research years revealed that the application of mineral and organic nitrogen fertilizers together with phosphorus-potassium fertilizers did not reveal significant differences between the variants, in contrast to the variants with HAC application together with phosphorus-potassium fertilizers in a tripoli environment, where there was a significant increase, as shown in table 3.

Determination of the nitrate content in the products confirmed the natural increase in the nitrate content from the applied nitrogen fertilizers for tilled crops. Thus, potato tubers increased their content by 19.5-50.7%, and fodder beet roots increased from 14.4 to 145.4 % compared to the control variant, Figure 3. Over the research years, a direct dependence of nitrate accumulation in potato tubers on fertilizers and zeolite-containing tripoli was revealed, but there was no excess MPC.

Table 3. Potato yield for 2012-2015, t/ha.

| Item No. | Variant | Culture | potato | fodder beet |
|----------|---------|---------|--------|-------------|
|          |         |         | tuber yield average, t/ha | deviation from control | average root crop yield, t/ha | deviation from control |
| 1        | Control (without fertilizers) | 17.5 | - | 22.36 | - |
| 2        | N60P60K60 | 26.5 | 9.0 | 28.32 | 5.96 |
| 3        | PKK (N60) + P60K60 | 27.2 | 9.7 | 34.46 | 12.10 |
| 4        | Tripoli (2 t/ha) + NPK | 32.0 | 14.5 | 35.86 | 13.50 |
| 5        | Tripoli (2 t/ha) + HAC + RK | 33.4 | 15.9 | 42.26 | 19.90 |
|          | HCP 05  | 1.78 | 5.62 |         |         |

Determination of the marketability of potatoes over the research years revealed that not only fertilizers had an impact on the marketability of potato tubers, but also the weather conditions of the growing season, as shown in table 4.

Table 4. Marketability of potato tubers on average over the years of the study, %

| Item No. | Variant | Years of study | Average for 2012-2015 | Deviation from control |
|----------|---------|----------------|-----------------------|------------------------|
|          |         | 2012 | 2013 | 2014 | 2015 |                     |                         |
| 1        | Control (without fertilizers) | 78.5 | 78.2 | 70.6 | 77.3 | 76.15 | - |
| 2        | N60P60K60 | 82.1 | 80.4 | 74.4 | 83.3 | 80.05 | 3.9 |
| 3        | PKK (N60) + P60K60 | 86.6 | 85.7 | 73.2 | 84.1 | 82.40 | 6.3 |
| 4        | Tripoli (2 t/ha) + NPK | 87.2 | 88.2 | 80.6 | 86.8 | 85.70 | 9.6 |
| 5        | Tripoli (2 t/ha) + HAC + RK | 90.1 | 90.3 | 82.3 | 88.5 | 87.80 | 11.7 |
|          | HCP 05  | 3.78 | 7.46 | 5.74 | 5.13 |         |                         |

Thus, in particular, the lack of moisture in the second and third part of July 2014 coincided with the budding and flowering phase and was reflected in a decrease in marketability by 1.2% in the variant.
having the application of horned ungulate crumbs as an organic fertilizer together with phosphorus-potassium mineral fertilizers compared to the variant having the mineral nitrogen fertilizer (ammonium nitrate).

The results obtained show that the application of mineral nitrogen fertilizer together with phosphorus-potassium mineral fertilizers contributes to the accumulation of nitrates in crop products compared with organic nitrogen fertilizer – (HAC) together with phosphorus-potassium mineral fertilizers both separately and in a tripoli environment (see figure 3 and figure 4).

**Figure 3.** Diagram of nitrate content in potato tubers by variants for 2012, 2013 and 2015, mg/kg.

**Figure 4.** Diagram of nitrate content in fodder beet roots by variants for 2012, 2013 and 2015, mg/kg.
Variants with HAC application had a positive effect on the accumulation of dry matter in potato tubers in comparison with variants with the application of the mineral nitrogen fertilizer ammonium nitrate. Thus, in 2012, the variant with the application of mineral nitrogen-phosphorus-potassium fertilizers had an accumulation of dry substances that was lower by 1.5 %, in 2013 – by 1.17 %, in 2015 – by 1.47 %.

When comparing the variant with the organic nitrogen fertilizer in a tripoli environment with the mineral nitrogen fertilizer (ammonium nitrate) in potato tubers, the accumulation of dry substances was greater by 2.3 % in 2012, by 2.5 % in 2013 and by 2.7% in 2015.

The study results revealed that root crops have an increase in their dry matter and sugar content, while potato tubers have an increase in their dry matter and starch content.

It is generally accepted that the application of mineral fertilizers in potato plantings and fodder beet crops reduces the dry matter content in root crops. However, our studies showed that this dependence is not observed in the variants with HAC application.

This can be explained by the gradual release of HAC nitrogen and its effective use by the plant (see figure 5 and figure 6). A similar relationship was observed based on the starch content in potato tubers.

![Dry matter %](image)

**Figure 5.** Diagram of dry matter content in potato tubers over the research years, mg/kg.

The structure of the barley crop sown the year after the tilled crops on the same plots revealed that in the aftereffect of the HAC variant compared to the mineral nitrogen fertilizer, there was an increase in the length of the stem and spike, grain count, weight of a thousand grains (M1000).

The highest yield of barley in the aftereffect occurred in the variant with the joint application of horned ungulate crumbs with phosphorus-potassium mineral fertilizers and zeolite-containing tripoli on tilled crops.
The study results show that zeolite-containing tripoli and HAC as an organic fertilizer together with phosphorus-potassium mineral fertilizers for potatoes and fodder beets can effectively use the nutrients of the fertilizers applied and for 2 years – the formation of a spring barley crop.

The economic efficiency of cultivating any crop is an expression of assessing the quality of application of all production factors based on a rational choice of the best combination and savings, the purpose of which is profit for the producer. The highest level of profitability of tubers in our study was noted in the variant with HAC (62.71%), in which it increased by 0.7% compared to the mineral fertilizer, despite a slight excess of labor and other costs. With the joint application of HAC in a tripoli environment, the profitability was 55.6%, and in the variant with the mineral nitrogen fertilizer – it was lower by 1.4%, as shown in Table 5.

Table 5. Economic indicators of the application of fertilizer and zeolite-containing tripoli on potatoes, average for 2012-2015.

| Variant | Yield, t/ha | Production costs per 1ha, RUB | Labor costs per 1ha, people/hour | Cost of 1 cent., RUB | Relative net income, RUB per 1 ha | Profitability level (payback), % |
|---------|-------------|-----------------------------|----------------------------------|----------------------|---------------------------------|---------------------------------|
| 1. Control (without fertilizers) | 17.5 | 46344.7 | 199.7 | 267.4 | 16941.3 | 36.0 |
| 2. N60 P60 K60 | 26.5 | 60678.0 | 286.6 | 231.1 | 37928.1 | 62.0 |
| 3. PKK60 + P60 K60 | 27.2 | 65145.8 | 292.9 | 241.9 | 41433.9 | 62.7 |
| 4. Tripoli (2t/ha)+ NPK | 31.9 | 83714.4 | 345.5 | 265.6 | 45855.7 | 54.2 |
| 5. Tripoli + HAC +PK | 33.4 | 88966.6 | 361.1 | 270.6 | 50074.6 | 55.6 |

Figure 6. Diagram of dry matter content in fodder beet roots over the research years, mg/kg.
The productivity of the grain potato-barley and fodder beet-barley link was the highest when fertilizing, but the highest yield of feed units and digestible protein was observed in the variant using HAC together with phosphorus-potassium mineral fertilizers in a zeolite-containing tripoli environment.

HAC application together with phosphorus-potassium mineral fertilizers, both in and outside a tripoli environment, contributed to the net energy income on potatoes by 1.3 times, and on fodder beets by 3 times more in comparison with the mineral nitrogen fertilizer.

The energy efficiency coefficient of variants with the organic nitrogen fertilizer on tilled crops and barley on average for the research years exceeded one, which proves the effectiveness of applying horned ungulate crumbs as nitrogen fertilizer and zeolite-containing tripoli for tilled crops in the grain-tillage link of crop rotation.

4. Conclusion
The results of the studies on the application of horned ungulate crumbs in the grain-tillage link of crop rotation revealed that the HAC fertilizer - meat-processing waste product is not inferior to the mineral nitrogen fertilizer in activity, and the application of zeolite-containing tripoli as a sorption-type ameliorant allows to effectively use the nutrient elements of fertilizers.

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