The impact of mineral fertilizers on the consumption of mineral elements and the Siberian-bred oat grain

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Abstract. This paper presents the findings of long-term field experiments to study the influence of increasing doses of mineral fertilizers on the technological and agrochemical features of Siberian-bred oat. The studies were performed in the forest-steppe zone of the Trans-Urals on leached chernozem. We have studied the varieties of cultivated oat of local selection: Talisman, Foma and Otrada on a natural soil preparation (control) and while applying fertilizers, in doses calculated to obtain the planned yield from 3.0 to 6.0 t/ha. It has been revealed that modern varieties of oat have genetic features for the assimilation of nutrients from the soil and fertilizers. It affects the content of protein, fat and starch in the grain. Accounting for the totality of indicators of the chemical composition, the Foma variety was distinguished. Its grain on fertilized variants contains: protein 10.8-15.3; fat - 3.0-3.6; starch - 33.0-45.7%. The use of mineral fertilizers results in an increase in the nitrogen content in grain and straw, and potassium - only in straw. The biological removal of nutrients depended on the level of mineral nutrition and the variety, giving ground for the development of a varietal system of fertilizers for oat in Western Siberia.

1. Introduction
The most significant factor in increasing the productivity of agrocenoses in Western Siberia is the use of mineral fertilizers. Nevertheless, the last decade has been defined by a very active export of mineral fertilizers and raw materials for their production. In order to meet the needs of the domestic agro-industrial complex, no more than 15% of all fertilizers produced in the country remain. It amounts to no more than 3.0 million tons of active substance. Some of these fertilizers continue to be unclaimed due to their high cost. This is reflected against the background of a total shortage of nutrients in the Russian arable land.

The fertility of the arable lands of Western Siberia is significantly lower than the same soils of the European part of Russia [1, 2]. Despite the high cost of fertilizers, large farms in Siberia actively use them. For increasing the economic efficiency of fertilizers, precision farming and differentiated application of mineral fertilizers are currently being implemented. These activities optimize the mineral nutrition of agricultural crops, considering the peculiarities of soil fertility [3, 4, 5].

At the end of the XX century, 30% of the sown oat in the world were concentrated in Russia. This was the result of the active development of animal husbandry. Today, the area under oat is much smaller, but the positive trend of the expansion of the area under this crop is clearly visible. The reason for this is the restoration of animal husbandry and the transition of this branch of agriculture to modern technologies. The Russian Federation is located in the middle and northern latitudes of our planet, where oat is an irreplaceable and valuable forage crop. The nutritional value of oat is perfectly
balanced for farm animals and poultry. In Siberia, where there is an active increase in animal husbandry and poultry farming, the value of this crop is significantly higher than in the European part of Russia. The formation of new varieties created with the use of biotechnologies and molecular genetics has formed a solid base for feed production in Siberia [6, 7].

Oat is a culture that responds very strongly to an increase in the level of mineral nutrition. The potential yield of modern varieties of sown oat has reached 10 t/ha. However, it works only under the condition of a balanced mineral nutrition. In Western Siberia, the potential productivity of the most fertile soil as chernozem does not exceed 2.5 t/ha of oat. Mineral fertilizers can significantly increase yields with a high rate of return. Nevertheless, a scientifically validated approach to the selection of a fertilizer system is required. The traditional use of fertilizers in equal proportions of nutrients in Russia is economically unjustified. Thus, agrochemical research on a fertilizer system considering soil and climatic conditions and biological features of agricultural crops is the most appropriate and preferential not only for Siberia, but for the whole of Russia as a whole.

2. Materials and Methods

The study was performed at the experimental field of the Northern Trans-Ural State Agricultural University, which is located 10 km from the city of Tyumen. The soil of the site is leached chernozem, monor, and heavy loamy. The content of humus in the arable horizon is 7.5%; nitrate nitrogen - 5.5; labile phosphorus - 72; potassium - 180 mg/ kg of soil, which is common for Western Siberia [8, 9, 10].

The experiment scheme is given in Table 1. In the experiment, modern varieties of intensive oat were used, created at the Research Institute of the Northern Trans-Urals [11]. The varieties are characterized by a high potential yield, reaching 8.0 t/ha. For obtaining the planned yield from 3.0 to 6.0 t/ha, doses of mineral fertilizers were calculated using the elementary balance method. The calculation considered the actual nutrient content in the arable horizon and the biological removal of each element. In order to form the planned yield up to 6.0 t/ha, only the use of nitrogen and phosphorus was required. The availability of potassium at the experimental site was very high, so it was not introduced with fertilizers. The ammonium nitrate (nitrogen content – 34.5%) and amorphous, which has 12% of nitrogen and 52% of phosphorus, were used in the experiment.

| Varieties (factor A) | Fertilizers (factor B) |
|----------------------|------------------------|
| Talisman             | 1. Control, without fertilizers |
|                      | 2. N_60P_20 kg/ha (planned yield is 3.0 t/ha of oat) |
|                      | 3. N_90P_40 kg/ha (planned yield is 4.0 t/ha of oat) |
|                      | 4. N_150P_60 kg/ha (planned yield is 5.0 t/ha of oat) |
|                      | 5. N_200P_80 kg/ha (planned yield is 6.0 t/ha of oat) |

The chemical analysis of grain and oat straw was performed in the agrochemical laboratory of the University. Total nitrogen was defined by the technique of wet ozonation in sulfuric acid; phosphorus and potassium - by the technique of dry ozonation followed by dissolution of the mineral residue in hydrochloric acid. The protein in the grain was evaluated by the total nitrogen, by multiplying its content by a factor of 5.87. The fat content in the grain was determined by Soxlet; starch - by
polarimetric method; fiber - according to GOST 31675-2012. The data obtained from laboratory studies was subjected to mathematical processing by the method of variance analysis using the Microsoft Excel.

3. Results and Discussion

According to our research, modern varieties of oat respond differently to the natural fertility of arable land. The minimum yield at the control was recorded in the Talisman variety - 1.41 t/ha of grain (Table 1). The Foma variety, which was created at the same research institute, had a yield of 1.73 t/ha, which is 23% higher than the Talisman variety. It is essential to note the Otrada variety separately. On average, for two years, the grain harvest at the control group amounted to 1.85 t/ha. This variety stood out among the others because it responded strongly to weather conditions with a shortage of mineral nutrition. In a favorable 2020, its yield was 2.13 t/ha, and in 2021, which was characterized by a very severe drought during spring and summer, grain harvest was 25% lower.

![Figure 1](image-url)

**Figure 1.** The influence of mineral fertilizers on grain and straw yield of Siberian oat, 2020-2021, t/ha.

Variants: 1 – Control, without fertilizers; 2 – N60P20 kg of active substance per hectare (kg/ha); 3 - N90P40 kg/ha; 4 - N150P60 kg/ha; 5 - N200P80 kg/ha.

The use of fertilizers at a dose of N60P20 kg of active substance per hectare ensured the formation of a yield of up to 3.0 t/ha of grain of the studied oat varieties. If the level of mineral nutrition increases, the role of weather conditions in the formation of the oat harvest began to manifest itself clearly. Accordingly, in the variant where fertilizers were applied at a dose of N90P40 kg/ha, which were supposed to provide 4.0 t/ha of grain, the actual yield in 2020 and 2021 differed considerably. This was most noticeable in the Talisman variety. Its grain harvest amounted to 4.31 and 2.63 t/ha, respectively. The yield of the Foma and Otrada varieties ranged for a lesser extent, which gave the desired result in an average of two years.

The development of a high soil preparation due to the application of mineral fertilizers (options 4 and 5) does not ensure the planned yield of more than 4.0 t/ha of the studied varieties. The actual grain harvest did not reach 4.90 t/ha.

Straw yield is an essential indicator from both an academic and a practical point of view. Nutrients are also consumed for its formation. They can refill soil reserves when plowing straw, as well as stabilize the humus state of arable land. In Western Siberia, straw has been ploughed relatively recently. Nevertheless, livestock farms still export it from fields to farms. According to studies, the yield of straw depends on the level of mineral nutrition and the oat varieties. At the natural soil preparation, where fertilizers were not used, the ratio of straw to grain in the Foma variety was 1.1, and in the Otrada – 1.3 points. The increase in the level of mineral nutrition. Mineral fertilizers
improve not only the grain harvest, but also the yield of straw. On the fertilized variants, the mass of straw of the studied varieties improved unevenly. In the Talisman variety, the maximum degree of straw growth was seen with an increase in the level of mineral nutrition. On the variant with the maximum saturation of fertilizers (N\textsubscript{200}P\textsubscript{80} kg/ha) the straw mass exceeded the grain yield by more than three times, reaching 5.54 t/ha. Its ratio to grain was 1.4 points, which was also the maximum in the experiment. The same values were recorded on the Foma variety. The grain and straw yield were the maximum in the experiment. The Otrada variety was characterized by a smaller growth of straw under the same conditions. The biomass of straw in variants 4 and 5 was equal to 5.71 and 6.03 t/ha, respectively. The straw-to-grain ratio did not exceed 2.50 units, which positively defines this variety.

The chemical features of the grain, as our studies have shown, depend not only on the level of mineral nutrition, but also on the variety. The greatest value in grain is protein and starch. At the control one, the Talisman variety formed grain with a minimum protein content of 8.9%, and at the Foma and Otrada varieties - 10.8 and 10.2%, respectively (Table 2). If the applied doses of mineral fertilizers improved, the studied varieties formed grain with an increased protein content. As a result of the growth in yield, the protein yield per unit area was positively affected. Its harvesting on the variant with the use of N\textsubscript{150}P\textsubscript{60} (the planned yield of 5.0 t/ha) reached 734 kg/ha for the Foma variety, while 497 kg/ha for the Talisman. Further increase in the level of mineral nutrition did not improve the protein content in the grain.

The varietal features of the ash content in the grain  of the studied varieties and the reliable influence of the level of mineral nutrition were not observed. This indicator varied from 2.6 to 3.0%.

Table 2. The chemical features of the sown oat at different levels of mineral nutrition, 2020-2021.

| Variants       | Protein   | Fat   | Starch | Fiber   | Ash   |
|----------------|-----------|-------|--------|---------|-------|
|                | %         |       |        | %       |       |
| **Variety: Talisman** |           |       |        |         |       |
| Control, without fertilizers | 8.9 | 126 | 2.2 | 30.0 | 13.7 | 3.0 |
| N\textsubscript{60}P\textsubscript{20} | 9.9 | 295 | 2.5 | 30.7 | 12.3 | 2.7 |
| N\textsubscript{90}P\textsubscript{40} | 10.9 | 377 | 3.1 | 35.3 | 10.4 | 2.7 |
| N\textsubscript{150}P\textsubscript{60} | 12.5 | 497 | 3.1 | 36.1 | 9.6 | 2.7 |
| N\textsubscript{200}P\textsubscript{80} | 12.7 | 504 | 3.1 | 38.6 | 9.7 | 2.7 |
| **Variety: Foma** |           |       |        |         |       |
| Control, without fertilizers | 10.8 | 187 | 3.0 | 33.0 | 12.0 | 2.7 |
| N\textsubscript{60}P\textsubscript{20} | 11.5 | 389 | 3.1 | 35.8 | 9.6 | 2.6 |
| N\textsubscript{90}P\textsubscript{40} | 13.4 | 544 | 3.6 | 42.2 | 9.6 | 2.6 |
| N\textsubscript{150}P\textsubscript{60} | 15.0 | 734 | 3.4 | 45.7 | 9.2 | 2.6 |
| N\textsubscript{200}P\textsubscript{80} | 15.3 | 700 | 3.3 | 45.3 | 9.5 | 2.6 |
| **Variety: Otrada** |           |       |        |         |       |
| Control, without fertilizers | 10.2 | 188 | 2.8 | 30.0 | 13.3 | 3.0 |
| N\textsubscript{60}P\textsubscript{20} | 11.2 | 362 | 3.2 | 32.4 | 10.4 | 2.6 |
| N\textsubscript{90}P\textsubscript{40} | 14.1 | 561 | 3.5 | 38.1 | 10.2 | 2.6 |
| N\textsubscript{150}P\textsubscript{60} | 14.0 | 667 | 3.4 | 44.3 | 9.6 | 2.7 |
The chemical analysis demonstrated that the varieties of cultivated oat initially differ in the nitrogen content in the grain. This is also true of other researchers who have studied the dynamics of nitrogen and protein accumulation in oat [12]. The minimum nitrogen content was 1.52% for the Talisman variety grown without fertilizers (Table 3). Under the same conditions, the nitrogen content in the grains of Foma and Otrada was significantly higher and reached 1.84 and 1.73%, respectively.

The improvement in the level of mineral nutrition had a positive effect on the accumulation of nitrogen in the grain. Its maximum content in the experiment was recorded on the Foma variety – 2.61%, while in the Talisman grain – 2.17%.

The variance analysis demonstrated that the share of the variety (factor A) in nitrogen accumulation is 26%, and fertilizers (factor B) – 52%. The interaction of factors A and B was not revealed (F_{fact} < F_{theor}). The smallest significant difference in the nitrogen content in the grain is 0.30%.

Like nitrogen, phosphorus also actively accumulates in oat in the form of organic substances. In our studies, the phosphorus content in the grain of the studied oat varieties with different levels of mineral nutrition diversified slightly – from 0.94 to 1.05%.

The chemical analysis demonstrated that the varieties of cultivated oat initially differ in the phosphorus content of the grain. The smallest significant difference between the variants was 0.17%.

Table 3. Nitrogen, phosphorus and potassium content in grain and straw of oat at different levels of mineral nutrition, % of air-dry weight, 2020-2021.

| Variants                  | Grain   | Straw   |
|---------------------------|---------|---------|
|                           | N       | P_{2}O_{5} | K_{2}O | N       | P_{2}O_{5} | K_{2}O |
| Varieties: Talisman       |         |         |        |         |         |        |
| Control, without fertilizers | 1.52    | 0.95    | 0.68   | 0.40    | 0.25    | 0.70   |
| N_{60}P_{80}              | 1.68    | 0.96    | 0.70   | 0.40    | 0.27    | 0.90   |
| N_{90}P_{40}              | 1.85    | 0.95    | 0.70   | 0.43    | 0.26    | 1.10   |
| N_{150}P_{60}             | 2.13    | 1.02    | 0.72   | 0.57    | 0.25    | 1.10   |
| N_{200}P_{80}             | 2.17    | 0.98    | 0.66   | 0.63    | 0.28    | 1.00   |
| Varieties: Foma           |         |         |        |         |         |        |
| Control, without fertilizers | 1.84    | 0.96    | 0.72   | 0.39    | 0.24    | 0.80   |
| N_{60}P_{80}              | 1.96    | 0.94    | 0.77   | 0.37    | 0.26    | 1.10   |
| N_{90}P_{40}              | 2.28    | 1.05    | 0.72   | 0.32    | 0.26    | 1.20   |
| N_{150}P_{60}             | 2.55    | 0.96    | 0.68   | 0.43    | 0.25    | 1.00   |
| N_{200}P_{80}             | 2.61    | 1.04    | 0.69   | 0.51    | 0.25    | 1.00   |
A.A. Kazak's research shows that in well-ripened grain crops, the nitrogen content in straw is minimal [13]. An additional amount of it specifies the incompleteness of the maturation processes at the physiological level, which can result in a decrease in the technological and sowing qualities of the grain [14, 15]. The Foma variety was distinguished in our studies by the minimum nitrogen content in the straw in relation to Talisman and Otrada. This gives the right to assert that in the conditions of the forest-steppe of Western Siberia, the Foma variety has irrefutable advantages in terms of ripeness when using high doses of mineral fertilizers.

The amount of potassium content in straw is also determined by the level of soil preparation. The introduction of low doses of fertilizers (N 60P20) had a positive impact. This indicator varied from 0.6 to 0.8%. With a further improvement in the doses of fertilizers, the potassium content in the straw increased, reaching 1.10-1.20%. While experimenting, there was no significant effect of the varieties on the potassium content. This is also true for phosphorus. Its content in straw of different oat varieties was characterized by resistance - 0.22-0.28%.

The varietal features of sown oat in terms of the efficiency of nutrient intake from soil and fertilizers are very well traced by the overall removal. It considers the content of nutrients in grain and straw per unit area. In the course of the conducted studies, it was revealed that the total nitrogen removal of the Talisman variety increases from 28 to 121; Foma - 39-152; Otrada - 40-149 kg/ha (tab.4).

Recalculating the removal per unit of yield, it can be concluded that there is no fundamental difference between the studied varieties. If oat is grown on a natural soil preparation and fertilizers are used in a dose N60P20 kg/ha, then the biological removal is 20-24 kg/t of grain. With a higher level of nutrition, which ensures the formation of a yield of 4.0 t/ha, the biological removal of the Talisman remains at 23 kg/t, while Foma and Otrada have 13% higher. A further improvement in the level of mineral nutrition mitigates the varietal difference in biological nitrogen removal, which differs in the range of 29-32 kg/t of grain.

The total phosphorus removal also improves with an increase in the level of mineral nutrition in all studied varieties. Talisman absorbed 18 kg of phosphorus on a natural soil preparation, while Otrada absorbed 23 kg/ha, which is 28% higher. The same pattern can be traced on variants with high doses of fertilizers. The maximum total phosphorus removal was 63 kg/ha.

The removal of phosphorus per ton of grain differed in the range from 12 to 17 kg by varieties and variants. The Foma variety is highlighted. Its biological removal was 15-17, while the Talisman and Otrada had 12-14 kg/t of grain. Based on the data obtained, it can be argued that the biological removal of phosphorus by oat is a varietal feature and does not depend on the level of mineral nutrition.

The biological removal of potassium ranged from 15-23 kg/t of grain, regardless of the variety. Nevertheless, the ranking according to the level of nutrition demonstrates a certain dependence on the soil preparation.

### Table 4. Removal of nitrogen phosphorus and potassium by various varieties of cultivated oat, 2020-2021.

| Variants          | N    | P2O5 | K2O   |
|-------------------|------|------|-------|
|                   | kg/ha| Per 1 ton of | kg/ha | Per 1 ton of | kg/ha | Per 1 ton of |
| Control, without fertilizers | 1.73 | 0.97 | 0.70 | 0.32 | 0.22 | 0.60 |
| N60P20            | 1.91 | 0.95 | 0.70 | 0.35 | 0.26 | 0.70 |
| N90P40            | 2.40 | 0.98 | 0.68 | 0.37 | 0.25 | 0.90 |
| N150P60           | 2.39 | 1.03 | 0.75 | 0.44 | 0.25 | 1.10 |
| N200P80           | 2.44 | 1.00 | 0.73 | 0.59 | 0.27 | 1.00 |
| Variety: Talisman                  | grain | grain |
|----------------------------------|-------|-------|
| **Control, without fertilizers** | 28    | 20    |
| N<sub>60</sub>P<sub>20</sub>     | 66    | 22    |
| N<sub>90</sub>P<sub>40</sub>     | 81    | 23    |
| N<sub>150</sub>P<sub>60</sub>    | 116   | 29    |
| N<sub>200</sub>P<sub>60</sub>    | 121   | 31    |

| Variety: Foma                    | grain | grain |
|----------------------------------|-------|-------|
| **Control, without fertilizers** | 39    | 23    |
| N<sub>60</sub>P<sub>20</sub>     | 80    | 24    |
| N<sub>90</sub>P<sub>40</sub>     | 106   | 26    |
| N<sub>150</sub>P<sub>60</sub>    | 152   | 31    |
| N<sub>200</sub>P<sub>60</sub>    | 147   | 32    |

| Variety: Otrada                  | grain | grain |
|----------------------------------|-------|-------|
| **Control, without fertilizers** | 40    | 21    |
| N<sub>60</sub>P<sub>20</sub>     | 75    | 23    |
| N<sub>90</sub>P<sub>40</sub>     | 112   | 28    |
| N<sub>150</sub>P<sub>60</sub>    | 139   | 29    |
| N<sub>200</sub>P<sub>60</sub>    | 149   | 32    |

4. Conclusion

According to the conducted studies, varietal features of the formation of chemical properties of grain and biological removal of elements of mineral nutrition of oat were determined. They change significantly under the influence of mineral fertilizers. The Foma variety forms grain with a maximum protein content of 10.8-15.3%; fat - 3.0-3.6% and starch 33.0-45.7%. Its biological removal is: N - 23-32; P - 12-13; K - 16-21 kg / t of grain. The Otrada variety has similar indicators of grain quality and biological removal. The Talisman variety is inferior to the Foma and Otrada in all indicators of grain quality. However, its biological removal has no significant differences.

If modern varieties of intensive oat are introduced into production, it is essential to additionally indicate the varietal characteristics of nutrient absorption, in order to develop an adapted fertilizer system for them.

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