The Influence of Macro- and Micronutrient Fertilizers on the Productivity of Meadow Clover in the Conditions of the Upper Volga Region

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Abstract. The research was carried out on the experimental field of the FSBEI of HE “Tver State Agricultural Academy” in 2019 and 2020. It was found that the application of pure microelement fertilizers Aquamix ST and Aquarin 5 allowed obtaining a statistically significant increase in the yield of green mass of meadow clover under favorable agro-climatic conditions on soils poor in microelements. The highest yield was noted on plots with clover treated with pure Aquarin 5 (57.90 t/ha) per cut. The use of Aquarin 5 increases the yield of clover by 22.20–48.80%, and in terms of mineral fertilizers in a full dose of N50P50K50 - by 4.80–24.30%. Small rates of mineral fertilizers N25P25K25 did not have a significant effect on the yield of clover, and an increase to N50 led to a negative result. The economic efficiency of the combined application of chelated and complex fertilizers is lower than the use of physiologically active substances in their pure form on soils poor in microelements.

1. Introduction

The world practice of agricultural sectors development and many researchers [1, 2, 3, 4] have confirmed that the scientific approach to agriculture increases the productivity of agricultural crops and the productivity of animals. The Non-Chernozem zone of the Russian Federation, despite the prevalence of soils with a low level of natural fertility, widely uses intensive technologies for the cultivation of agricultural crops and the active development of precision farming. Most of this territory is located in the zone of sufficient and excessive moisture, however, the uneven distribution of precipitation and temperature fluctuations in the context of plant growth and development phases, which are hard to predict for a long period of time, cause sharp fluctuations in the productivity of agrophytocenoses over the years.

Perennial legumes are traditionally the most important component in the structure of the cultivated areas of the Non-Chernozem region. Despite the prevalence of short crop rotations or the long period use of grasses in the farms of the region, perennial legumes are the component that allows maintaining soil fertility, while giving high yields of balanced feed and improving the phytosanitary condition of fields even in risky farming conditions.

The value of meadow clover cultivation, as one of the most frequently used components of perennial grasses, is evident, first of all, in obtaining high-quality balanced feed, which plays a decisive role in creating a stable forage base for livestock farms [5, 6, 7, 8]. In the climatic conditions of the Central Region of the Non-Chernozem Zone clover gives high yields of hay – 4 – 6 t/ha and more.
Clover needs a moderately warm climate with even winters, without large temperature fluctuations. It demands a stable snow cover for a good overwintering and does not respond well to thaws. This culture grows well on soils with a neutral and close to neutral environment, sufficiently provided with moisture. It poorly tolerates saline and waterlogged areas, sandy soils are also not recommended for the clover cultivation. When the pH of the soil solution is below 4.50, it usually falls out [9].

A characteristic ability of legumes in general and clover in particular is their symbiosis with bacteria that synthesize nitrogen from the air. Studies indicate the ability of clover to partially absorb hard-to-absorb phosphates from the soil [10].

Like any other high-yielding crop, clover yields good if it gets enough mineral nutrients, water, heat and light. Without the optimization of these factors, it is impossible to achieve the maximum productivity of clover crops.

It is noted that in a number of cases the application of micronutrient fertilizers increases the resistance of plants to unfavorable natural and climatic conditions, to damage by pests and diseases, and provides an increase in yield by 10–12% [11].

One of the promising directions for increasing the productivity of the agrophytocenosis of leguminous grasses is the use of microelements in a chelated form. Chelates are water-soluble organic substances that are practically not adsorbed by the soil absorbing complex and remain available to plants for a long time. In addition, the chelating substances themselves (EDTA, DTPA, EDDA), penetrating the cells of plant leaves, can participate in the metabolic processes of plants.

The research purpose is to define the role of macroelements of mineral fertilizers and physiologically active substances (microfertilizers) in the formation of clover yield and to determine their effect on the main characteristics of the obtained feed and the fertility of sod-podzolic soils in short-rotation fodder crop rotation in the Upper Volga region.

2. Materials and methods
Clover studies were carried out on the experimental field of the Tver State Agricultural Academy in 2019–2020. The research program provided for the establishment of a three-factor field experiment with a randomized placement of variants by the method of split plots in triplicate.

The study of the formation of agrophytocenosis is carried out in a grain-steam-grass crop rotation with a short rotation period. The structure of the sown area is as follows: cereals 33%, full fallow (vetch-oats) 33%, grasses (red clover) 33%.

The experiment was laid on sod-medium-podzolic loamy sand residual calcareous on moraine loam soil (table 1).

In the initial state, there is a low content of a number of nutrients: Ca, Mg, Cu, and B. The content of organic matter is at a low level, which is typical for poorly cultivated, low-humus sod-podzolic soils.

| Table 1. Some agrochemical characteristics of the topsoil. |
|-----------|---|---|---|---|---|---|---|---|---|
| Organic matter | Ca | Mg | Hr | P2O5 | K2O | S | Mn | Cu | Fe | B | Zn |
| % | meq/100 g of soil | mg/kg of soil |
| 1.87 | 3.88 | 0.69 | 2.18 | 377 | 90 | 6.49 | 2 | 1.73 | 134 | 0.25 | 1.67 |

The soil of the experimental plot has a slightly acidic reaction of the environment (pH 5.2–5.4), suitable for cultivation of meadow clover. Productivity is determined by the method of sampling on the root for non-tilled crops.

The experiment plan:
Factor A – rotation crops:
1. Full fallow – vetch-oats;
2. Oats with clover seeding;
3. 1st year clover

Crop varieties: Krechet sowing oats, Trio meadow clover, Lgovskaya 22 spring vetch.
Factor B – mineral macrofertilizers:
1. Without fertilization (control). Symbol (0)
2. Introduction of \( \frac{1}{2} \) of the calculated rate of a.s. \( N_{25}P_{25}K_{25} \) kg/ha. Symbol (NPK 25)
3. Introduction of the full rate of a.s. \( N_{50}P_{50}K_{50} \) kg/ha Symbol (NPK 50)

Factor C – foliar fertilizing with physiologically active substances (PAS) (figure 1):
1. Without adding microelements in chelated form, symbol (0)
2. Crop treatment with Aquamix ST
3. Treatment with Aquarin 5

![Figure 1. Comparative number of nutrients in the studied PAS, %.

Compound NPK fertilizer containing 16% nitrogen, phosphorus and potassium was used as the main mineral fertilizer applied for pre-sowing cultivation. Physiologically active substances Aquarin 5 and Aquamix ST were applied by spraying plants with 1% working solution in the tillering phase of oats (simultaneously with clover) with a working fluid flow rate of 100 l/ha.

The mathematical processing of experimental data was carried out using the software package Statistica Advanced.

3. Research results
The experimental field of Tver State Agricultural Academy is located in the vicinity of the city of Tver. The climate of the region is temperate continental, characterized by relatively warm summers, moderately cold winters with stable snow cover and distinct transitional seasons. Tver region belongs to the zone of sufficient moisture. Two thirds of precipitation per year falls in the form of rain, one third – in the form of snow [12].

Clover is a low heat-demanding crop with an optimal temperature for growth and development in the range of 18–20 °C. This crop is more demanding in terms of moisture supply, but does not tolerate its excess. In general, the climatic conditions of the Upper Volga region allow obtaining high yields of perennial grass crops, including meadow clover.

The agro-climatic conditions of the growing season of clover, which developed directly during the years of research, are presented in figures 2 and 3.
The heat supply (figure 2), starting from the phase of clover regrowth (table 2), in 2019 was at a level sufficient for active growth. The average air temperature values exceeded the standard values by an average of 3–7 °C until the third decade of June (the end of the stemming phase and the beginning of budding), when the air temperature dropped below the average long-term values by 2.70–4.90 °C. Nevertheless, the supply of heat during this period was close to the optimal values.

The growing season of 2020 was colder in the first half of the clover growth and development period, but its regrowth was recorded 11 days earlier than in 2019. This is due to an uncharacteristically warm winter for this region and an almost complete absence of snow cover (snow melt from the fields was recorded on March 26–30, 7–13 days earlier than usual). The heat supply was higher than the average for the region in early May and throughout the summer period, right up to harvesting. Temperatures fell below normal in the interval from the 2nd decade of May to the 1st decade of June, which, together with unfavorable conditions in terms of moisture supply, led to an extension of the stemming phase and an increase in the duration of clover biomass accumulation. In general, the temperature conditions in 2019 and 2020 were favorable for the growth and development of clover and did not prevent a high yield level.

**Table 2.** Agrometeorological characteristics of the growing season and development phase of meadow clover, 2019–2020.

| Values                        | Spring regrowth | Stemming | Budding | Beginning of flowering | Full flowering |
|-------------------------------|-----------------|----------|---------|------------------------|----------------|
| 2019r., root rosette phase    | 27.04–12.05     | 13.05–25.06 | 26.06–05.07 | 06.07–11.07 | 12.07–17.07 |
| Average for a decade 2019     | 16.70           | 17.40    | 15.60   | 14.70                  | 14.20          |
| Average for a decade 2020     | 251             | 748.80   | 156     | 88.20                  | 85.20          |
| Precipitation, mm             | 5.44            | 35.60    | 29.50   | 12                     | 12             |
| Hydrothermal coefficient      | 0.22            | 0.48     | 1.89    | 1.36                   | 1.41           |
| The onset of phenological phases | 27.04–12.05 | 13.05–25.06 | 26.06–05.07 | 06.07–11.07 | 12.07–17.07 |
| Number of days (86)           | 15              | 43       | 10      | 6                      | 6              |
| 2020r., root rosette phase    | 12.07–17.07     |          |         |                        |                |
A distinctive feature of the 2019 growing season was a prolonged drought with extremely low rainfall. The total amount of moisture was 94.54 mm, which is an extremely low indicator for meadow clover. Low moisture availability from regrowth to budding led to significant losses in the accumulation of green mass (table 3), which is noticeable when comparing the yield for 2019 and 2020. Until the second decade of June, the amount of precipitation did not exceed 33% of the climatic norm.

In 2020, the amount of precipitation fell within the recommended range for meadow clover cultivation (303.6 mm). This factor did not limit the studied crop in development, which made it possible to compare the studied factors in more favorable conditions (figure 4).

Despite the unfavorable weather conditions prevailing in the first year of the research, the data in table 3 indicate that in the first and second years, in a number of variants, a significant increase in the yield of green mass of meadow clover was observed.

Additional treatment of clover with Aquamix ST according to the N\textsubscript{50}P\textsubscript{50}K\textsubscript{50} background, as well as the application of N\textsubscript{25}P\textsubscript{25}K\textsubscript{25} in pure form, allowed to obtain a statistically significant increase in the yield of meadow clover in the first year of research: the difference between the variants with the compound NPK fertilizer applied in pure form and with the addition of the microelement fertilizer Aquamix ST was 11.70 %.

| Table 3. Dependence of the accumulation of green mass of meadow clover at the end of the growing season on mineral fertilizers and foliar fertilizing, t/ha, 2019–2020. |   |
| --- | --- | --- | --- |
| Foliar fertilizer | Background | 0\textsuperscript{1} | NPK 25 | NPK 50 |
| Vegetation 2019 HCP\textsubscript{0.05}= 2.16 | 0\textsuperscript{2} | 26.73 | 25.92 | 29.93 |
| | Aquamix ST | 29.35 | 29.87 | 26.39 |
| | Aquarin 5 | 32.67 | 28.93 | 31.36 |
| Vegetation 2020 HCP\textsubscript{0.05}= 4.77 | 0\textsuperscript{2} | 38.90 | 46.40 | 39.92 |
| | Aquamix ST | 53.60 | 44.90 | 54.80 |
| | Aquarin 5 | 57.90 | 40.50 | 49.60 |
Current effect: $F(4.18) = 5.8422$, $p = 0.00340$.
Decomposition of the hypothesis PASxNPK, LS average.
Vertical bars equal 0.95 confidence intervals.

**Figure 4.** Mutual influence of NPK and PAS factors, t/ha of green mass 2020.

A high yield was noted on plots with clover treated with Aquarin 5 in its pure form (+22.20%) and according to the background of mineral fertilizers in a full dose together with the same preparation (+17.30%). Small application rates of mineral fertilizers $N_{25}P_{25}K_{25}$ did not have a significant effect on the yield of clover, and their increase to $N_{50}P_{50}K_{50}$ showed the same result as the treatment of clover with Aquamix ST in its pure form.

Variance analysis of multivariate experience shows a statistically significant increase in yield obtained in the second year of the study. LSD$_{0.05}$ of partial differences (4.78) also confirms the reliability for two factors in six variants of the experiment. The F-criterion for the factors “Background NPK” and “PAS” confirms their influence on the accumulation of green mass of clover, both separately and jointly.

As in the first year of observations, the greatest effect was achieved when using PAS Aquarin 5 in its pure form (+48.80%). High results were noted when adding Aquamix ST in combination with the background $N_{50}P_{50}K_{50}$ (+40.90%) and when using it in its pure form (+37.80%).

There was a significant increase in the accumulation of feed units and protein in green masses per unit area (figure 5) in the case of using foliar fertilizers with chelates.

**Table 4.** Dynamics of changes in the content of crude fiber relative to the control in the green mass of meadow clover, 2020.

| Foliar fertilizer | Background |   |   |
|-------------------|------------|--|--|
|                   |            | 0$^2$ | NPK 25 | NPK 50 |
| 0$^2$             | 0          | –0.09 | 1.72   |
| Aquamix ST        | –0.56      | 3.05  | 0.47   |
| Aquarin 5         | –0.64      | –1.30 | 1.33   |
An increase in the mass fraction of digestible protein after the introduction of PAS Aquamix ST in its pure form and Aquarin 5 according to the NPK background (+0.05–0.11 g kg of dry weight to control) in terms of 1 kg of dry matter was not statistically confirmed.

The application of pure PAS Aquarin 5 provided an additional increase in digestible protein in the amount of 0.92 t/ha, Aquamix ST was less effective (+0.66 t/ha), but its use also turned out to be a highly effective method.

![Graph showing accumulation of digestible protein in 2020, t/ha.]

**Figure 5.** Accumulation of digestible protein in 2020, t/ha.

The introduction of complex fertilizers and foliar feeding with chelated forms of microelements accounts for a significant part of the costs that make up the cost of the finished product. It is also important to take into account that the calculation of the profitability of one or another agricultural method in relation to perennial grasses has a significant difference from most field crops, associated with a longer period of use of crops and the transfer of costs for their cultivation to subsequent years.

In our case, meadow clover was used in short-period crop rotation for one year following sowing. Thus, in calculating the economic efficiency, the costs of cultivation were transferred from the cover crop and taken into account in the cost of green mass. The calculations were carried out for 100 hectares of area.

The calculation of costs in the cultivation of meadow clover for green mass was carried out taking into account the standards of material and labor costs for production and tariff rates for wages, prices for fuels and lubricants, seeds and mineral fertilizers at purchase prices relevant for the third quarter of 2019 and 2020 (figure 6).
Regardless of the weather conditions of the growing seasons of 2019 and 2020, cultivation of clover during the first year of use made it possible to obtain high profitability in all studied variants, which is typical for both this kind of crop and for perennial herbage in general. [13].

It has been established that the main items of expenditure in the cultivation of clover of the first year of use are the cost of transporting the additional crop obtained and the introduction of complex mineral fertilizers. Transportation of a larger volume of green mass to the place of further processing and storage, all other things being equal (option 0NPK), led, despite a 2.20-fold decrease in the unit cost, to a 2.50-fold drop in the level of profitability. Nevertheless, the high economic efficiency of cultivating clover without fertilizing does not lead to obtaining target yield indicators; according to this criterion, it loses significantly to other options, and therefore cannot be considered the most effective way of cultivating this crop.

There are significant differences in the effectiveness of replacing complex fertilizers with foliar feeding with chelates. The use of PAS in its pure form in the first year of research made it possible to increase the profitability of production by 306.30% (Aquamix ST) and 222.70% (Aquarin 5) in comparison with the most effective use of complex fertilizer at a dose of N25P25K25 in its pure form, even if the best results in terms of yield and increased harvesting costs.

A significantly higher level of profitability and a notional net income was obtained in 2020, a more favorable year for clover growth. Treatment of plants with PAS in pure form showed the best results among the studied options, also due to the exclusion from the technological process of operations associated with the purchase and application of mineral fertilizers. The best indicators of profitability and minimum cost of green mass of clover were also noted for the variants with the use of pure preparations Aquamix ST (604.8%) and Aquarin 5 (685.5%) in recommended doses. At the same time, the prime cost decreased by 1.44 and 1.37 times as compared to the previous year, respectively, while maintaining the highest indicators of crop formation.

The use of PAS and compound NPK fertilizer mixtures increased production costs, which led to a decrease in payback and showed less effective results and a decrease in the level of profitability by 2.69-3.27 times compared to the best options. The use of chelates in combination with relatively high doses of mineral fertilizers for meadow clover is not recommended from an economic point of view.
4. Conclusion
The use of preparations containing microelements in a chelated form in their pure form is a highly effective way to increase the productivity of meadow clover, not only comparable in results with the application of mineral fertilizers in doses up to N50P50K50, but also exceeding them at a significantly lower application cost.

The relatively low efficiency of the applied high (N50P50K50) doses applied in pure form and in combination with PAS complex fertilizers can be explained by the imbalance in the mechanisms of nitrogen fixation of meadow clover, associated with a large amount of readily available nitrogen compounds in the topsoil of the corresponding variants at the beginning of the growing season. Similar results were obtained by a number of authors [14] with the introduction of N60P60K60.

Treatment of clover crops with Aquarin 5 on sod-medium podzolic soil, even without the use of complex mineral fertilizers, made it possible to significantly increase the accumulation of green clover mass in the second year of research. High efficiency is also noted when using Aquamix ST. However, despite the significantly higher content of trace elements in this preparation, its use turned out to be less effective. Presumably, it is due to the high responsiveness of clover to the addition of such nutrients as sulfur and magnesium together with Aquarin 5.

The relatively low efficiency of the applied mineral fertilizers is explained by the low and very low content in the topsoil of a number of microelements important for the growth and development of clover (Mg, S, B, Cu), which are not part of the complex fertilizers used in the experiment.

Two-year data show the high efficiency of the application of the studied PAS on the sod-podzolic soils of the Upper Volga region, especially in the case of a low content of the components of these fertilizers in the soil. The use of compound NPK fertilizer in this case is an agricultural technique aimed not so much at obtaining an increase in yield, as at compensating for the removal of NPK with the crop alienated from the field, which, together with the plant residues left after the clover, provides an increase in fertility for subsequent crops of the crop rotation.

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