Fertilizers, plant density and nutritional properties of corn grain

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Abstract. The article presents data on the influence of an increasing plant density of an early-ripening corn hybrid on the biochemical composition and fodder properties of grain, depending on the level of mineral nutrition. It is shown that the highest protein supply was noted for the grain obtained in the variants with nitrogen feeding; the increase in crude protein in comparison with the variants on the natural agrobackground was 1.56%. The use of complete mineral fertilization had no advantages over a single application of nitrogen-phosphorus fertilizers; against these nutritional backgrounds, the increase of 0.97-1.05% was obtained in relation to the unfertilized agricultural background. As the crops crowd, there is a tendency for the crude protein content in the grain to increase. Over the years of testing, the stable influence of the conditions of mineral nutrition and the plants density on the content of crude fiber, crude ash and nitrogen-free extractive substances has not been established. The grain with a higher crude fat content was obtained with the introduction of complete mineral fertilization, and the crowding of the crops led to the decrease in its content in the grain.

1. Introduction

In many countries of the world, grain production is oriented towards the cultivation of food and feed grains, with particular preference given to corn. The priority of its cultivation was determined by two main qualities - the possibility of a constant increase in yield while improving the production technology and the high energy value of grain when feeding to most farm animals. It is important not only to increase the grain yield but also to improve its quality in order to obtain grain with high fodder values. The optimal doses of fertilizers for corn are determined not only by yield increments but also by the effect on the product quality [1, 2]. The direction and intensity of biochemical processes in ripening grain depend on the supply of nutrients to plants. With the introduction of scientifically grounded doses of fertilizers, the mineral nutrition of plants is improved, which contributes to the mobilization of the physiological resources of plants and the increase in the quality of the grown grain. High-quality corn grain, first of all, should have a high content of protein and lysine and other essential amino acids. The lack of these substances in the diets of animals leads to a decrease in their productivity. Grain quality is mainly created during the period of grain filling, when the products of photosynthesis are transformed into storage substances. Therefore, during this period, plants require increased nitrogen nutrition, i.e., providing them with nitrogen-containing mineral nutrients in optimal quantities. That is why it is important to ensure optimal nitrogen nutrition during the entire growing season of maize, and also to...
combine the main application of fertilizers with nitrogen top-dressing [3, 4, 5]. The protein content of the grain is strongly influenced by weather conditions, and among the agrotechnical methods that affect this indicator, fertilizers stand out for their effectiveness [6, 7, 8, 9].

2. Materials and methods

The studies of the doses and periods of mineral fertilizers application and plant density effect on the corn biochemical composition were carried out in 2015-2017 on leached heavy loamy chestnut soils (black soil) with increased content of nitrogen and phosphorus and a high supply of potassium, the reaction of the soil solution was weakly acidic. The field experiment was carried out in four replicates by the method of split plots with the following factors and gradations: Factor A - fertilizer dose: 1 - N₀P₀K₀ (control); 2 - N₁₂₀P₀; 3 - N₀P₀₀ + N₃₀ (for top-dressing in the phase of 6-7 maize leaves); 4 - N₁₂₀P₀₀K₆₀. Factor B - plant density: 1. - 60 thousand pcs/ha; 2 - 70 thousand pcs/ha; 3 - 80 thousand pcs/ha; 4 - 90 thousand pcs/ha; 5 - 100 thousand pcs/ha. The area of the plots of the first order was 140 m². The area of the plots of the second order was 28 m². The placement of variants was systematic. The object of research was the early ripe corn hybrid ROSS 199 MB (FAO 190). The sowing was carried out with a row spacing of 0.70 m. The plant density was formed in the phase of full germination. The cultivation technique was generally accepted for chernozem soils. The forecrop was winter wheat after black fallow. Fertilizers were applied during the first pre-sowing cultivation.

3. Results and discussion

The three years of studies showed that the protein supply of grain varied both depending on the cultivation method and on the weather conditions during the growing season. Among climatic factors, moisture conditions have the greatest effect on the protein content in grain: the less moisture and the higher the temperature, the higher the protein content. As the grain ripens, the content of crude protein and, accordingly, protein nitrogen decreases in it, while starch increases. This can be explained by the intensification of the process of carbohydrates (total sugars) entering the grain in the last stages of its development. The influence of N₁₂₀P₀₀ and N₁₂₀P₀₀K₆₀ on the accumulation of protein in grain was approximately equal, its content varied from 10.72 to 11.34%. The least protein-rich grain was obtained on unfertilized variants. Due to the improvement of the conditions of mineral nutrition, the increase of 1.39-2.06% was obtained. A similar pattern was noted in subsequent years of the research, however, the increase in protein compared to the variants on the natural agricultural background was 0.96-1.59% for the growing season in 2016, and 0.57-1.01% - in 2017. It should be noted that in 2015-2016 there was a clear tendency to the increase in the protein content of grain as the density of plants grew, and in 2017, the increase in protein was observed up to the density of 80 thousand pieces/ha, and then there was a decrease in the protein content of grain. On average, over the years of the experiment, the highest protein supply was noted for grain obtained in the variants with nitrogen fertilization, the increase compared to variants on the natural agricultural background was 1.56% (Table 1). The use of complete mineral fertilization had no advantages over a single application of nitrogen-phosphorus fertilizers; against these nutritional backgrounds, the increase of 0.97-1.05% was obtained in relation to the unfertilized agricultural background. As the crops thicken, there is a tendency for the crude protein content in the grain to increase.

Crude fiber is difficult to digest and poorly absorbed by the body. The high fiber content lowers the nutritional value of plant feed. As the grain ripens, the fiber content naturally decreases, which is confirmed by the results of the studies. It was found that the content of crude fiber in grain underwent significant changes depending on the weather conditions of the year of study. Less ripe and digestible grain was obtained in conditions of the active temperatures lack in 2017, the content of crude fiber varied from 5.77 to 6.15%. In these conditions, a negative effect of the thickening of crops on the quality of grain was noted. Against the background of the application of mineral fertilizers, especially when a part of the nitrogen is transferred to the root feeding, the increase in the content of crude fiber was observed. In the conditions of better heat supply during the growing season, grain with a lower fiber content (4.42-5.11%) was obtained, and there was a tendency toward the decrease in the digestibility of grain with the
increase in plant density. On average, over the years of the research, no stable effect of the conditions of mineral nutrition and plant density on the content of crude fiber was revealed (Table 1).

Table 1. Biochemical composition of corn grain, average for 2015-2017.

| Fertilizer dose | Plant stand, thousand pcs/ha | % in dry matter | Nitrogen-free extractive substances |
|----------------|-----------------------------|-----------------|-----------------------------------|
|                |                             | Crude protein   | Crude fiber | Crude fat | Crude ash |                           |
| N₀P₀K₀         | 60                          | 9.03            | 5.25       | 4.36      | 1.76      | 79.61                        |
|                | 70                          | 9.16            | 5.22       | 4.27      | 1.74      | 79.60                        |
|                | 80                          | 9.28            | 5.26       | 4.22      | 1.77      | 79.47                        |
|                | 90                          | 9.38            | 5.01       | 4.19      | 1.82      | 79.60                        |
|                | 100                         | 9.41            | 5.16       | 4.25      | 1.64      | 79.53                        |
| N₁₂₀P₉₀        | 60                          | 10.15           | 5.08       | 4.30      | 1.87      | 78.59                        |
|                | 70                          | 10.23           | 5.07       | 4.16      | 1.82      | 78.72                        |
|                | 80                          | 10.31           | 5.03       | 4.26      | 1.81      | 78.59                        |
|                | 90                          | 10.39           | 5.11       | 4.19      | 1.87      | 78.44                        |
|                | 100                         | 10.43           | 5.07       | 4.08      | 1.85      | 78.56                        |
| N₉₀P₉₀ + N₃₀   | 60                          | 10.63           | 5.24       | 4.18      | 1.74      | 78.21                        |
|                | 70                          | 10.67           | 5.28       | 4.31      | 1.74      | 77.99                        |
|                | 80                          | 10.92           | 5.10       | 4.28      | 1.71      | 78.00                        |
|                | 90                          | 10.88           | 5.19       | 4.27      | 1.73      | 77.93                        |
|                | 100                         | 10.96           | 5.26       | 4.15      | 1.68      | 77.95                        |
| N₁₂₀P₉₀K₆₀    | 60                          | 10.01           | 5.02       | 4.29      | 1.70      | 78.99                        |
|                | 70                          | 10.08           | 5.15       | 4.35      | 1.59      | 78.42                        |
|                | 80                          | 10.31           | 5.06       | 4.23      | 1.56      | 78.84                        |
|                | 90                          | 10.30           | 5.07       | 4.22      | 1.71      | 78.71                        |
|                | 100                         | 10.39           | 5.24       | 4.10      | 1.74      | 78.52                        |

Fats are high in calories, so they are a source of energy in the body of animals. As the grain ripens, its fat content rises. As shown by the results of biochemical analysis, grain with a higher content of fat was obtained in the conditions of 2015. The content of crude fat was 4.36-5.02% according to the variants of the experiment, and there was a tendency to a decrease in its concentration in the grain with an increase in the plant density and nitrogen top-dressing, which indicates an extension of the vegetation and grain ripening period. This pattern persisted in 2016, and the fat content in grain varied from 4.01% to 4.35%. Under conditions of a lower heat supply in the growing season of 2017, the grain did not reach full ripeness by harvest, and the fat content was 3.75-4.06%. Under these conditions, the most fat-rich grain was obtained with the introduction of complete mineral fertilization, and the grain obtained by transferring a part of nitrogen to top-dressing had a lower fat accumulation. For all the backgrounds of mineral nutrition, there is a clear pattern of reducing the fat content during the thickening of crops. On
average, over three years of the research, grain more provided with crude fat was obtained with the introduction of complete mineral fertilization, and the thickening of crops led to a decrease in its content in the grain (Table 1).

The total amount of ash characterizes the mineral nutritional value of the feed. There are few ash substances in plant feed and they are unevenly distributed. As for the accumulation of the mineral part of the dry matter of grain, it should be noted that with insufficient precipitation in 2015, nitrogen fertilization contributed to a greater accumulation of ash elements. In 2016, which was more favorable in terms of humidification, against the background of a single application of nitrogen-phosphorus fertilizers, an increase in the content of raw ash by 0.23-0.54% was recorded compared to other agricultural backgrounds. In 2017, the content of crude ash changed little.

That depended on the doses and timing of the application of mineral fertilizers and plant density. On average, over three years of the experiment, a clear pattern of the influence of the level of root nutrition and plant density on the mineral composition of the grain was not noted; only a tendency for the increase in the content of raw ash was revealed with a single application of nitrogen-phosphorus fertilizers (Table 1).

The group of nitrogen-free extractive substances (NFES) includes all nitrogen-free substances, with the exception of fat and crude fiber. The main part of the nitrogen-free extractive substances of feed are carbohydrates - water-soluble (sugars) and water-insoluble (starch). In general, according to this indicator, it can be said that among all nutrients contained in grain, NFES occupy the first place, their share accounted for 78.10-80.09% of dry matter of grain. Moreover, the doses of mineral fertilizers and the density of planting on the concentration of NFES had an insignificant effect (Table 1). The weather conditions during the growing season had a greater effect on the accumulation of nitrogen-free extractive substances. In a more favorable hydrothermal regime of 2016, the NFES content in grain was the highest - 78.57-80.09%. And the least of NFES was contained in the feed obtained under the conditions of moderate growing temperatures in 2017 - 78.10-79.14%.

The harvest of crude protein depended on grain yield more than on protein content. On average, over the years of the research, the transfer of a part of nitrogen to top-dressing increased the protein harvest by 305 kg/ha, or by 79.2%, compared with the unfertilized agricultural background (Figure 1).
98 kg/ha or 16.6%. With the introduction of potassium into the composition of nitrogen-phosphorus fertilizers, an additional 50 kg/ha or 8.4% of protein was obtained.

In terms of the yield of crude fat, the advantage was over the variants against the background of complete mineral fertilization, which was mainly due to the higher grain yield in these options. The increase to the variants without fertilization averaged 80 kg/ha or 76.9%. The variants with nitrogen-phosphorus fertilizers were slightly inferior, where the collection of crude fat increased by 54.8-61.5% relative to the unfertilized agricultural background. The yield of crude fat grew up to a plant density of 80 thousand pcs/ha, and then it decreased.

Corn is an important energy supplier in the diets of farm animals. Exchangeable or physiologically useful energy is understood as the amount of feed energy that goes to support the life of the animal, the synthesis of products, and the energy of products. Due to its high energy content, corn grain is an irreplaceable component of compound feed for all types of animals and poultry. The corn grain obtained in the experiment was distinguished by a rather high content of metabolic energy, the value of which varied within rather narrow limits - from 12.4 to 12.6 MJ/kg of dry matter. The studied methods of cultivation did not affect the energy supply of the forage. In terms of the yield of metabolizable energy, the best options were the use of full mineral fertilizer at a dose of N<sub>120</sub>P<sub>90</sub>K<sub>60</sub> and fractional nitrogen application, where the yield accumulated energy by 26.07-26.90 GJ/ha more than in unfertilized options.

As the number of plants per unit area increased on all agricultural backgrounds, with the exception of variants with nitrogen fertilization, the yield of metabolic energy also increased.

4. Conclusion
The highest supply of protein was noted for grain obtained in variants with nitrogen fertilization; the increase over variants on the natural agricultural background was 1.56%. The use of complete mineral fertilizers had no advantages over a single application of nitrogen-phosphorus fertilizers; against these nutritional backgrounds, the increase of 0.97-1.05% was obtained in relation to the unfertilized agricultural background. As the crops thicken, there is a tendency for the crude protein content in the grain to increase. The transfer of a part of nitrogen to top-dressing increased the protein yield by 305 kg/ha or by 79.2% compared to the unfertilized agricultural background.
Over the years of testing, no stable influence of the conditions of mineral nutrition and the density of plants on the content of crude fiber, nitrogen-free extractives, and crude ash was revealed. The grain more provided with crude fat was obtained with the introduction of complete mineral fertilization, and the thickening of the crops led to the decrease in its content in the grain.

The studied cultivation techniques did not affect the energy supply of grain, and in terms of the exchange energy output, the best variants were the use of complete mineral fertilizer at the dose of $N_{120}P_{90}K_{60}$ and fractional nitrogen application.

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