

## Productivity and technological features of sugar beet root crops when applying of different doses of nitrogen fertilizer under the conditions of the middle Cis-Ural region

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### Abstract

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The aim of the research was to determine the optimal dose of nitrogen fertilizer to get maximum yields of root crops with high technological features. For the first time under the conditions of the middle Cis-Ural region the yield and dynamics of top and root mass of sugar beet hybrid Hercules with different doses of nitrogen fertilizer were determined. Technological features of sugar beet roots such as content of potassium, sodium, alpha-amine nitrogen, sugar and purified sugar and also sugar gross collection, standard sugar losses in molasses, purified sugar gross collection when applying of different doses of nitrogen fertilizer were determined. The dependence of the content of molasses-forming substances on nitrogen fertilizer dose was revealed. The indicator of purified sugar gross collection was used to determine the optimal dose of fertilizer. As a result the high economic efficiency of sugar beet cultivation for the purified sugar gross collection with nitrogen fertilizer application at a dose rate of 160 kg a.i. per hectare was established.

**Keywords:** sugar beet; nitrogen; fertilizer dose; productivity; technological features; sugar; purified sugar; gross collection

### Introduction

Sugar beet is cultivated worldwide under various growing conditions, generally on the more fertile soils (Hoffmann et al., 2009). Sugar beet is the only source of raw materials for industrial sugar production in Russia, including the Republic of Bashkortostan. Every year in the Republic of Bashkortostan sugar beet is cultivated on the area of 55-75 thousand ha and therefore sugar beet growing is important in crop production (Gabitov et al., 2018; Ismagilov & Islamgulov, 2016; Lubova et al., 2018). Proper application of mineral

fertilizers in accordance with the biological characteristics of plants and soil and climatic conditions of beet growing zones is precondition in sugar beet cultivation (Draycott, 2006; Hoffmann, 2006; Islamgulov, 2014). Numerous experiments carried out without application of nitrogen, phosphorus and potassium at different stages of sugar beet development have shown that in the absence or lack of one of these elements the yield is significantly reduced (Islamgulov et al., 2014; Chien et al., 2016; Chatterjee, 2018).

Of all macronutrients, nitrogen has the greatest impact on the yield and quality of sugar beet roots (Ismagilov &

Islamgulov, 2000; Hoffmann, 2010; De Bruyn et al., 2017; Akhiyarov et al., 2018). Nitrogen nutrition has the greatest value and it is the main factor affecting the quality of beets (Islamgulov, 2014; Koch et al., 2016; Jacobs et al., 2018; Kuznetsov et al., 2018). Insufficient nitrogen nutrition at the beginning of vegetation reduces the yield of root crops (Islamgulov & Bakirova, 2017; Barzegari et al., 2017; Marlander et al., 2018). This is especially noticeable when the growth of the aboveground part is strongly oppressed for a long period. If nitrogen is available to plants in large quantities it stimulates a continuous increase in reducing sugar content and deterioration in juice purity (Islamgulov, 2015; Schneppel & Hoffmann, 2016; Abyaneh et al., 2017). Subsequently experiments showed that this was due to the increased use of carbohydrates in the synthesis of protein substances (Varga et al., 2017; Hoffmann & Kenter, 2018; Kristek et al., 2018; Ismagilov et al., 2018).

Due to the fact that significant progress has been made in the selection of sugar beet, the study of productivity formation and technological features of sugar beet, the establishment of the optimal dose of nitrogen fertilizer taking into account the content of molasses-forming substances is a crucial task. Analysis of the results of studies conducted over the past 30-40 years in Russia, including the middle Cis-Ural region to determine the optimal dose of nitrogen fertilizers showed that there were significant differences in the recommendations. There are differences between different authors and the same authors in different years of research. Only sugar content of root crops was considered in calculating the technological qualities of sugar beet. The content of major molasses-forming substances such as potassium, sodium and alpha-amine nitrogen was hardly taken into account (Islamgulov et al., 2018). Therefore the aim of this research was to determine the optimal dose of nitrogen fertilizer for production of root crops with high technological features.

## Material and Methods

### Field trials

Field studies were carried out in the period 2015-2017 on the farm "Orlyk" in the Karmaskalinsky district of the Republic of Bashkortostan. The objects of research were sugar beet hybrid Hercules breeding company "Syngenta" (Switzerland) and nitrogen fertilizer dose. Hercules is genetically diploid hybrid of N-type (normal). The hybrid is highly resistant to boltering and exhibits moderate resistance to the root borer (*aphanomyces*). It is characterized by high technological features of the root and plasticity under contrasting growing conditions.

The choice of this hybrid was justified by the fact that it is included in The State Register of Selection Achievements in the Ural region of the Russian Federation, and The State Register in the Republic of Bashkortostan. In the field experiment the factor-dose of nitrogen fertilizer was studied. Ammonium nitrate (containing at least 34.4% of nitrogen) was used as a nitrogen fertilizer. The field experiment was carried out as follows: variant 1 – dose  $N_{40}$  (control); variant 2 – dose  $N_{80}$ ; variant 3 – dose  $N_{120}$ ; variant 4 – dose  $N_{160}$ ; variant 5 – dose  $N_{240}$ .

### Sample treatment and analyses

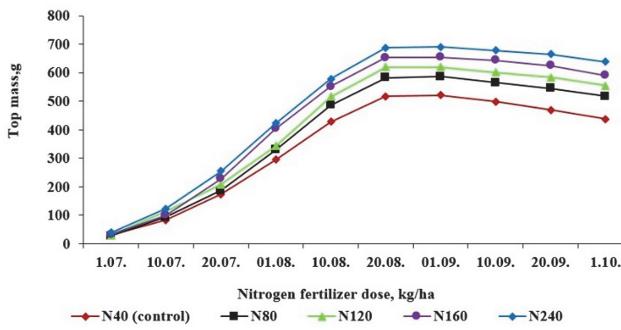
The sugar content of beets was determined by the method of cold hydrogenation of saccharimeter – polarimeter. To determine the alpha-amine nitrogen we used Staneck and Pavlas's method modified by Wininger and Kubadinov which was based on the measurement of optical density using a spectrophotometer. Potassium and sodium content was determined by Silin method on a flame photometer. The standard sugar losses in the formation of molasses were calculated by the formula of Braunschweig derived by Buchholz et al. (1995). The purified sugar content was calculated as the difference between sugar content and standard sugar losses in molasses. Sugar gross collection was defined as the product of yield and sugar degree. Purified sugar gross collection was calculated as the product of yield and purified sugar content.

### Statistical evaluation

The analysis of field experiment results at the second stage was carried out in the form of mathematical processing of the ordered results of field experiment. The aim was to obtain statistical estimates of the resulting indicators, to identify the obtained empirical dependences, mathematical confirmation of the validity of the scientific hypothesis and substantiation of scientific conclusions. Organized repetition allows to neutralize the impact of variability of the experimental site on the results of the experiment and to provide the possibility of reducing the error of experiment in the process of variance analysis of experimental data separating the variation in yield variants from random variation. We conducted variance analysis to determine the significance of the results for each factor. The essence of the variance analysis is the division of variance (sum of squared deviations) and the total number of degrees of freedom into parts corresponding to the structure of the experiment and evaluation of the action significance and interaction of the studied factors. The use of these methods allowed to prove the validity of the variant differences in the field experiments, the connection between the studied factors and to determine the impact model of one or more variable factors.

## Results and Discussion

Research results of the dynamics of top mass at different doses of nitrogen on average for 2015-2017 showed that nitrogen amount in the composition of mineral fertilizer was essential in the intensity of the growth of sugar beet above-ground mass. The top mass increased with increasing doses of nitrogen. This consistent pattern is distinctly seen by the end of growing season (Figure 1).



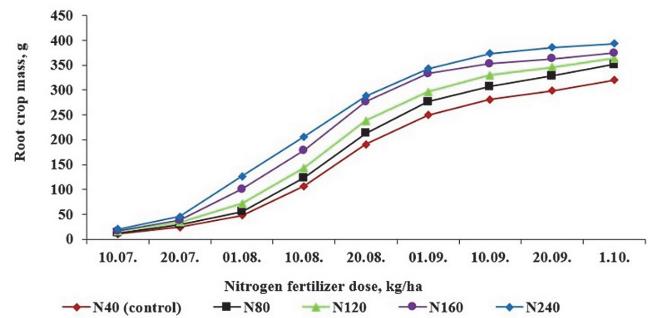
**Fig. 1. Dynamics of top mass during the growing season (2015-2017)**

The highest growth rate was observed from the first decade of July to the second decade of August. Then the intensity of top growth began to decline but the top mass continued to increase. The maximum top mass reached in the third decade of August and was in the variants from 522 to 690 g. The largest top mass was in the variant N<sub>240</sub> and the smallest one was in N<sub>40</sub>. Since the beginning of September the top mass began to decline due to leaf dying-off and air temperature decrease. Also at this time the reverse transition of nutrients from leaves to roots (reutilization) began. The intensity of sugar beet root growth depended on the period of development and the growth continued throughout the growing season until the harvest. Until mid-July the growth was relatively slow. After that there was an intensive accumulation of root crop mass and it continued until the first decade of September. Decrease in the rate of accumulation of root crop mass occurred only at the end of the growing season (Figure 2). The study of the dynamics of root crop mass showed its direct dependence on the dose of nitrogen fertilizer.

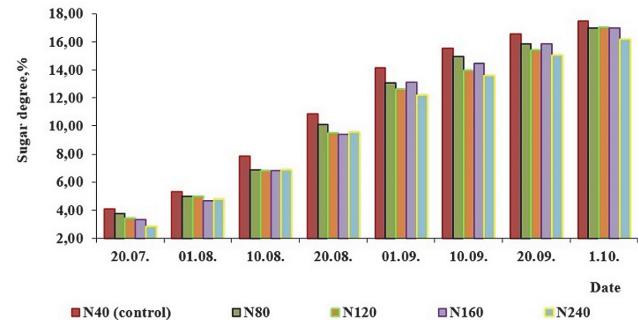
The smallest root crop mass at the time of harvesting was in variant N<sub>40</sub> and the largest one in variant N<sub>240</sub>. Root crop mass increased with increasing nitrogen doses.

Sugar accumulation was gradual and the most intensive period was from early August to early September. In dry years sugar degree of root crops increases (Figure 3).

The rate of sugar accumulation was relatively lower at the beginning and end of the growing season. Sugar degree

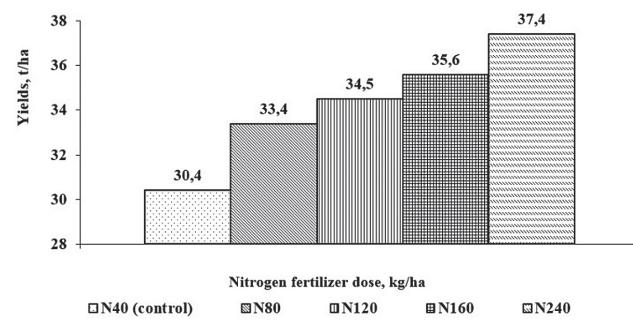


**Fig. 2. Dynamics of root crop mass during the growing season (2015-2017)**



**Fig. 3. Dynamics of sugar content in sugar beet roots (2015-2017)**

of root crops at the time of harvesting varied depending on the dose of nitrogen fertilizer from 16.20% (N<sub>240</sub>) to 17.48% (N<sub>40</sub>). In sugar degree there was an inverse correlation from the dose of nitrogen fertilizer in contrast to the top and root mass. Sugar degree decreased with increasing doses of nitrogen. The yield increase of sugar beet crops depending on the year and the variant was 2.45-8.6 t/ha (Figure 4). The highest yield of sugar beet roots was formed in variant N<sub>240</sub> (37.4 t/ha) and the lowest one was in variant N<sub>40</sub> (30.4 t/ha). Correlation analysis of experimental data for 3 years also showed



**Fig. 4. Root crop yields (2015-2017)**

that there was a positive relationship between nitrogen fertilizer dose and the yield of sugar beet roots in the studied range. This relationship is relatively weak ( $\eta = 0.44$ ) which is due to the strong influence of agrometeorological conditions on the yield.

### Sugar content in root crops

On average for three years the maximum sugar content in root crops was in the variant N<sub>40</sub> (17.48%) and the lowest one was in N<sub>240</sub> (16.20%). In other variants there was a relatively similar sugar content (16.98-17.06%) (Figure 5).

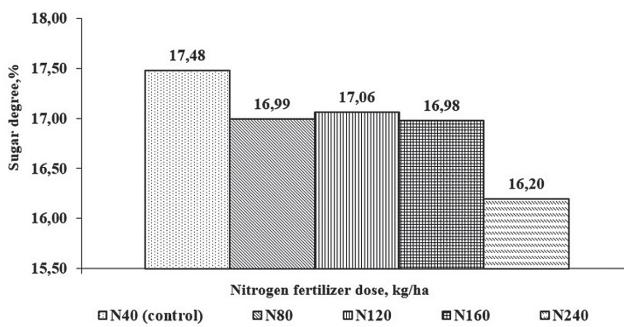


Fig. 5. Sugar degree of root crops (2015-2017)

Correlation analysis of experimental data for 3 years showed that there was an inverse (negative) relationship between nitrogen fertilizer dose and sugar content in sugar beet roots in the studied range. Although this relationship was weak ( $\eta = -0.41$ ). Thus the higher nitrogen fertilizer doses, the less sugar degree in sugar beet roots. Nitrogen fertilizer dose influenced the potassium content in root crops (Figure 6). On average for three years the potassium content in experiment variants varied from 4.73 mmol to 5.40 mmol per 100 g of crude mass.

Correlation analysis showed that there was a positive relationship between nitrogen fertilizer dose and potassium content in sugar beet roots. The relationship between these

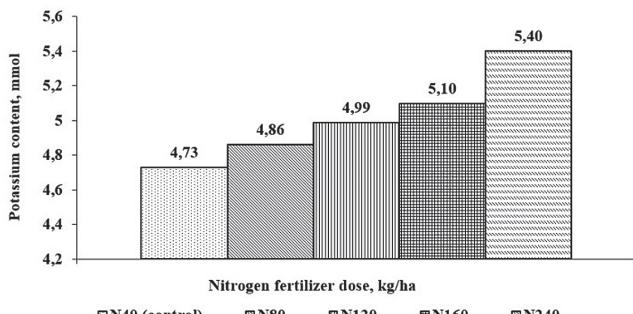


Fig. 6. Potassium content in root crops, mmol/100 g of crude mass (2015-2017)

indicators was moderate ( $\eta = 0.53$ ). The more nitrogen fertilizer doses, the more potassium content in crude mass of root crops. The difference between the variants of the experiment was 0.13-0.67 mmol.

Nitrogen fertilizer dose affected the sodium content in sugar beet roots (Figure 7). The highest sodium content was in variant N<sub>160</sub> (1.05 mmol) and the lowest one was in variant N<sub>40</sub> (0.80 mmol). Variants N<sub>80</sub>, N<sub>120</sub>, N<sub>240</sub> differed slightly (0.88-0.95 mmol). The difference in comparison with the control was from 10 to 31.2%.

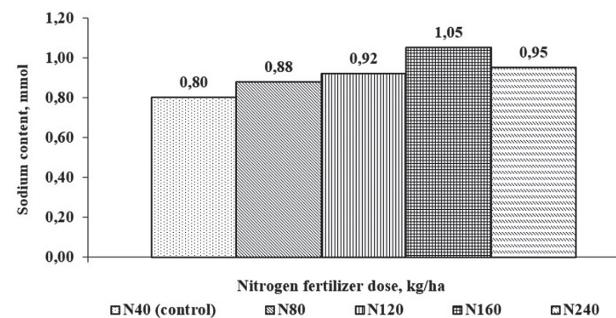


Fig. 7. Sodium content in root crops during harvesting, mmol/100 g of crude mass (2015-2017)

Between nitrogen fertilizer dose and sodium content in sugar beet roots in the studied range there is dependence in the form of parabola. The relationship between these indicators is moderate and the correlation index ( $\eta$ ) is 0.66. As nitrogen fertilizer dose (N<sub>160</sub>) increases, the sodium content in the crude mass of root crops increases and then decreases.

On average for 2015-2017 alpha-amino nitrogen content in roots was different and depended on the number of applied nitrogen fertilizer (Figure 8). Its lowest content was noted in the control variant and the highest one was at the maximum nitrogen dose. The content of alpha-amino nitrogen in variant N<sub>160</sub> exceeded the control by 1.43 times and in variant N<sub>240</sub> exceeded by 2.23 times.

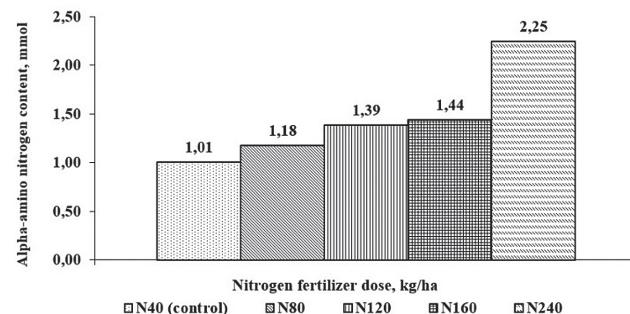
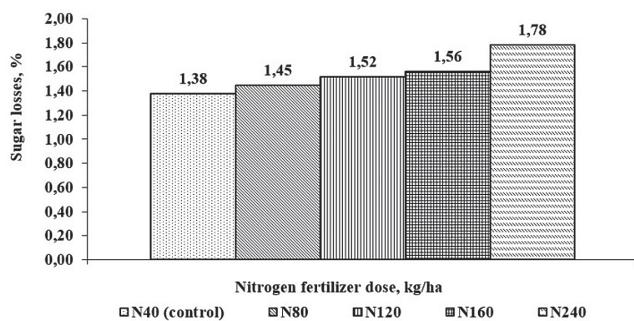


Fig. 8. Alpha-amino nitrogen content in root crops at harvest time, mmol/100 g of crude mass (2015-2017)

Correlation analysis showed that there was a strong positive relationship between nitrogen fertilizer dose and alpha-amino nitrogen content in sugar beet roots ( $\eta = 0.96$ ).

The increase in alpha-amino nitrogen content apparently is due to the fact that the ability of sugar beet tissues to synthesize protein is in correlation with the change in the content of total and protein nitrogen and heavily dependent on mineral nutrition. Increased nitrogen fertilizer doses caused intense growth of both root and sugar beet tops. As a result beet roots accumulated a lot of nitrogenous substances especially alpha-amino nitrogen.

Nitrogen fertilizer dose significantly influenced sugar loss in molasses (Figure 9).

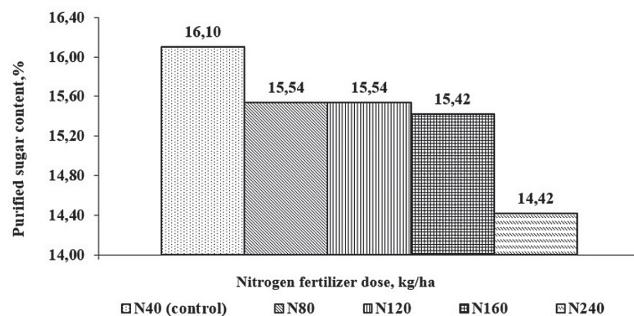


**Fig. 9. Standard sugar losses in the formation of molasses (2015-2017)**

Increasing nitrogen fertilizer dose increased the standard sugar loss in molasses. Variant  $N_{240}$  was characterized by the highest sugar loss exceeding the control at 0.40%. Sugar loss was primarily associated with high content of alpha-amino nitrogen and potassium in the roots.

Nitrogen fertilizer dose significantly influenced the content of purified sugar in root crops (Figure 10).

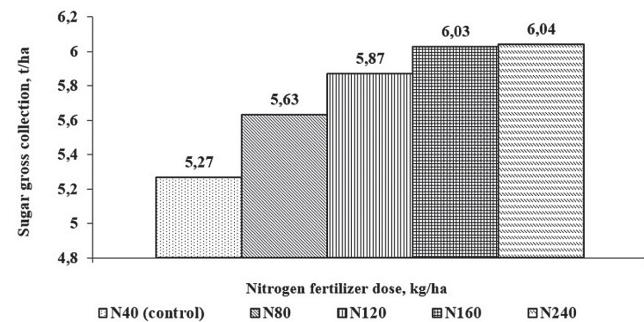
The highest content of purified sugar was in variant  $N_{40}$  (16.10%) and the lowest sugar content (14.42%) was in the maximum nitrogen dose in variant  $N_{240}$ . Variants  $N_{80}$  and



**Fig. 10. Purified sugar content in root crops (2015-2017)**

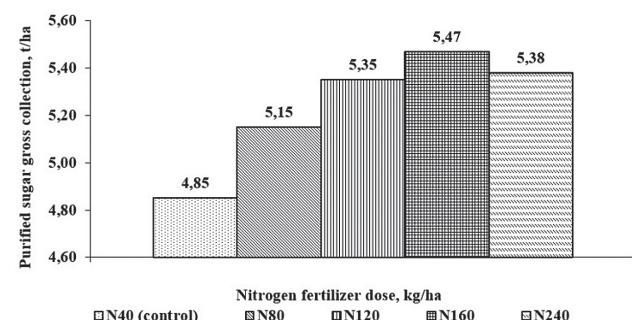
$N_{120}$  had the same sugar degree (15.54%). The difference between the variants ranged from -0.56 to -1.68%. Standard sugar losses in molasses increased with increasing nitrogen fertilizer doses.

Studies have shown that on average for 2015-2017 the maximum sugar gross collection occurred when using high doses of nitrogen fertilizers (variants  $N_{160}$  and  $N_{240}$ ) exceeding the control by 14.4 and 14.6% (Figure 11).



**Fig. 11. Sugar gross collection (2015-2017)**

Extra sugar yield ranged from 0.36 t/ha to 0.77 t/ha. Sugar gross collection increased with increasing nitrogen fertilizer doses. On average for 2015-2017 variant  $N_{160}$  showed the maximum gross collection of refined sugar (5.47 t/ha) and control variant  $N_{40}$  showed the minimum gross collection (4.85 t/ha). Sugar collection in variants  $N_{120}$  and  $N_{240}$  was relatively the same (5.35 t/ha and 5.38 t/ha) (Figure 12).

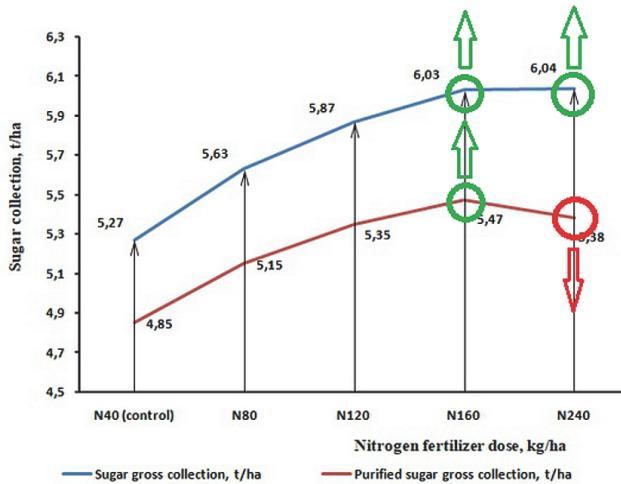


**Fig. 12. Purified sugar gross collection (2015-2017)**

The increase in purified sugar gross collection varied from 0.30 t/ha to 0.60 t/ha. The highest dose of nitrogen fertilizer (variant  $N_{240}$ ) did not give an increase in purified sugar gross collection since sugar loss in the molasses was high.

Studies have shown that purified sugar gross collection increases with increasing doses of nitrogen fertilizer to a cer-

tain limit. Calculations found that it is more correct to use refined sugar gross collection than sugar gross collection to evaluate sugar beet productivity (Figure 13). Thus the highest sugar gross collection was obtained in variant N<sub>240</sub> (6.04 t/ha). At the same time purified sugar gross collection with losses in molasses was higher in variant N<sub>160</sub>.



**Fig. 13. Sugar collection when applying of nitrogen fertilizer in different doses (2015-2017)**

A comparative analysis of the correlation coefficients of nitrogen fertilizer dose with productivity indicators and technological qualities of sugar beet roots showed positive and negative, weak, moderate and very strong degrees of relationship. In the studied limits nitrogen fertilizer dose is positively correlated with the yield, content of potassium, sodium, alpha-amino nitrogen, standard sugar losses in molasses, sugar gross collection and purified sugar gross collection. There was a negative correlation with sugar degree and purified sugar content. There was a negative correlation

with the sugar content and purified sugar. Moreover the effect of the nitrogen fertilizer dose on the content of alpha-amino nitrogen and standard sugar losses in molasses was very strong; the effect on the content of potassium, sodium and refined sugar was moderate (average); the effect on productivity, sugar content, sugar gross collection and purified sugar gross collection was weak.

Cost-effectiveness analysis of nitrogen fertilizer application on two different productivity indicators (sugar gross collection and purified sugar gross collection) also showed that to evaluate the productivity of sugar beet it is better to use purified sugar gross collection than sugar gross collection (Table 1). A higher cost-effectiveness (242%) was in variant N<sub>120</sub>, when calculating sugar gross collection. At the same time the calculation of the efficiency of purified sugar gross collection showed that the cost-effectiveness of variant N<sub>160</sub> (214%) was higher than variant N<sub>120</sub> (212%). Accordingly the application of nitrogen fertilizer at a dose of 160 kg a.i. per 1 ha was the most cost-effective cultivation of sugar beet.

We studied the mass of sugar beet tops. The indicator increased with increasing nitrogen fertilizer doses. The maximum top mass was in variant N<sub>240</sub>, the minimum one was in variant N<sub>40</sub>. The growth intensity of root crop mass increased with increasing nitrogen fertilizer doses, the largest mass of root crops at harvesting time was in variant N<sub>240</sub>. The more nitrogen fertilizer doses, the less sugar degree in root crops ( $\eta = 0.41$ ). Similar results were obtained in the studies of Rother (1998) and Hoffmann (2017).

The yield of sugar beet crops increased with increasing the nitrogen fertilizer dose although the correlation analysis showed a relatively small closeness of relationship ( $\eta = 0.44$ ) which is due to the influence of a more effective agrometeorological factor on the yield. The content of molasses-forming substances in sugar beet roots naturally increases with increasing nitrogen fertilizer dose. The closeness of relationship between the content of alpha-amino nitrogen and

**Table 1. Economic efficiency of sugar beet cultivation with different nitrogen fertilizer doses (Buzovyyazovo, on average for 2015-2017)**

Indicator	Experiment variants				
	N <sub>40</sub>	N <sub>80</sub>	N <sub>120</sub>	N <sub>160</sub>	N <sub>240</sub>
<i>Sugar gross collection</i>					
Sugar gross collection per 1 ha, t	5.27	5.63	5.87	6.03	6.04
Production value per 1 ha, RUB	94860	101340	105660	108540	108720
Cost effectiveness, %	225	237	242	241	224
<i>Purified sugar gross collection</i>					
Purified sugar gross collection per 1 ha, t	4.85	5.15	5.35	5.47	5.38
Production value per 1 ha, RUB	87300	92700	96300	98460	96840
Cost effectiveness, %	199	209	212	214	189

nitrogen fertilizer dose is very high ( $\eta = 0.96$ ), potassium and sodium are average ( $\eta = 0.53$  and  $\eta = 0.66$  respectively). The analysis of scientific works of Schnepel and Hoffmann (2016) also confirms the effect of nitrogen fertilizer on the sugar beet yield.

Standard sugar loss in molasses increased ( $\eta = 0.95$ ) with increasing nitrogen fertilizer doses. It was due to the increase in alpha-amino nitrogen and potassium content. Purified sugar content decreased ( $\eta = 0.53$ ) with increasing nitrogen fertilizer doses. Interpretation of results according to standard sugar losses agreed with the studies of Trimpler et al. (2017). Sugar gross collection increased ( $\eta = 0.39$ ) with increasing nitrogen fertilizer doses and it reached a maximum value in variant N<sub>240</sub>. The largest sugar gross collection was obtained in variant with nitrogen fertilizer dose N<sub>240</sub>. At the same time purified sugar gross collection taking into account losses in molasses is higher in variant N<sub>160</sub>. Correlation analysis showed that sugar gross collection increased with increasing nitrogen fertilizer doses to a certain limit ( $\eta = 0.30$ ). A similar interpretation of the studies is also given in the works of Hoffmann and Marlander (2005). To evaluate the productivity of sugar beet it is better to use purified sugar gross collection than sugar gross collection. A higher cost-effectiveness was in variant N<sub>120</sub>, when calculating sugar gross collection in comparison with application at a dose in variant N<sub>160</sub>. At the same time the calculation of the efficiency of purified sugar gross collection showed that the cost-effectiveness of variant N<sub>160</sub> was higher than variant N<sub>120</sub>. It is recommended to apply nitrogen fertilizer at a dose of 160 kg a.i. per 1 ha to obtain the largest purified sugar gross collection in the cultivation of sugar beet on leached chernozems of the middle Cis-Urals.

## Conclusion

It is recommended to apply nitrogen fertilizer at a dose of 160 kg a.i. per 1 ha to obtain the largest purified sugar gross collection in the cultivation of sugar beet on leached chernozems of the middle Cis-Urals. This dose of nitrogen fertilizer used in the experiments made it possible to harvest maximum yields (37.4 t/ha) of sugar beet roots with high technological qualities (content of sugar, potassium, sodium, alpha amino nitrogen) at the highest economic efficiency (214%).

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