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Productivity and Technological Qualities of Sugar Beet at Different Times of Harvesting Depending on Contamination and Freezing of Root Crops

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Abstract: The aim of the study is to establish the optimal harvesting time for obtaining the maximum yield of root crops with high technological qualities and high profitability in the conditions of the Southern forest-steppe of the Republic of Bashkortostan.The patterns of changes in the weight of the tops and roots, the yield of the hybrid of the sugar beet RMS-120 at various times of harvesting are revealed. The dependence of the productivity and technological qualities of sugar beet roots (potassium, sodium, alpha-amino nitrogen, sugar, purified sugar, standard losses of sugar in molasses, total sugar output, gross output of purified sugar) on the harvesting period is established. The degree of influence of the harvesting period on the contamination and freezing of the sugar beet root crops is calculated. To determine the optimal harvesting period, it is suggested to use the gross output of refined sugar, taking into account contamination and freezing of root crops. As a result, a high economic efficiency of sugar beet cultivation was established for the gross output of refined sugar, taking into account losses due to contamination and freezing of root crops during harvesting from October 10-25.

Key words: Suger beet, harvesting time, productivity, technological qualities, contamination, Russia

INTRODUCTION

The economic growth and welfare of the state depend to a large extent on the efficiency of the agricultural complex functioning in which the sugar beet subcomplex belongs to an important place as one of the highly industrial and energy-intensive industries. According to Hoffmann (2006), Morozov *et al*. (2016) and Islamgulov (2014) this branch of agriculture depends on the level development of the resource base organization, the state of economic relations within the subcomplex and state regulation.

In Russia, sugar beet is the main technical culture that provides raw materials to the sugar industry. In the researches of Ismagilov and Islamgulov (2016), Islamgulov (2014, 2015) the cultivated areas of sugar beet were analyzed which indicate that on the territory of Russia currently sugar beet is cultivated on an area of about 1 mill. ha including 50-55 thous. ha on the territory of the Republic of Bashkortostan.

One way to increase the production of sugar from its own raw materials is to reduce losses of root crops and sugar by harvesting at the optimal time. In different years, Marlander (1992), Bloch and Hoffmann (2003) and Trimpler *et al*. (2017) proved that in the technology of sugar beet cultivation to reduce losses of root crops, harvesting period is of primary importance.

Early harvesting of unripened beet is one of the reasons for the low sugar content and productivity of raw materials for processing. Also, early harvesting reduces the keeping quality of root crops. This fact is proved by such scientists as Islamgulov and Bakirova (2017a, b), Rother (1998) and DeBruyn *et al*. (2017).

Later, Hoffmann (2017), Draycott *et al*. (1974) and Islamgulov and Bakirova (2017) studied harvesting time, its technological qualities as well as contamination of root crops. In the course of their research, they concluded that sugar beet harvested at a later date technically ripe has a higher yield and technological quality and the purity of the juice reaches a higher level. At a later harvest, the strength of the connection of leaf stalks with the heads is reduced, they are easier to separate which helps to reduce the level of contamination of root crops. At the same time, late cleaning leads to increased pollution due to soil adherence.

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In the researches of Steinmetz *et al*. (1998), Hoffmann (2010), Islamgulov (2014) and Koch *et al*. (2016) studies of root crops freezing were made. The results of the research show that with the extension of the harvesting period, the number of frozen roots is increased. Frozenness promotes an increase in the loss of weight of conditioned root crops and a decrease in technological qualities.

Studies by Ismagilov and Islamgulov (2000), Hoffmann and Kenter (2018), Schnepel and Hoffmann (2016a, b) suggest that the harvesting in the optimal time allows not only to increase the yield and quality indicators of sugar beets but also reduce energy and labor costs when cultivating this crop.

In the Republic of Bashkortostan as Ismagilov and Islamgulov (2016), Islamgulov (2014) and Ismagilov and Islamgulov (2000) testify it is customary to start harvesting sugar beet on September 15. On the territory of the Republic of Bashkortostan the growing season is comparatively short (160-174 days) and in the sugar beet plants in contrast to many field crops, physiological processes do not stop. The accumulation of sugars in root crops occurs before the temperature changes through zero degrees in the autumn (October 24-29).

The experimental study by Morozov *et al*. (2016) and Islamgulov and Bakirova (2017a,b) proved that the sugar beet harvesting in late autumn due to strong soil moisture and low air temperature increases the contamination and freezing of roots. Contamination of root crops is one of the main criteria for the organization of sugar beet harvesting: their increased level increases labor costs and reduces the yield of root crops.

Analysis of scientific and methodological literature of foreign and domestic scientists showed that there is a need to study this issue in more detail in the conditions of our region. Proceeding from this, the aim of the research was to determine the optimal time for harvesting sugar beet to obtain the maximum yield of root crops with high technological qualities and high profitability in the conditions of the Southern forest-steppe of the Republic of Bashkortostan.

MATERIALS AND METHODS

Field experiments were conducted in 2015-2017. In the Irek Limited Liability Company (LLC) of the Karmaskalinsky District which is located in the Southern forest-steppe of the Republic of Bashkortostan. The object of the research is the productivity and technological quality of the sugar beet hybrid *Beta vulgaris* of the Russian selection of PMC-120 F1, a single-stage diploid hybrid of normal (N) type.

Harvesting of root crops was carried out from September 10 to November 20 (8 harvesting periods): the 1 harvest time is 10.09, the 2 harvest time is 20.09 (control), the 3 harvest time is 01.10, the 4 harvest time is 10.10, the 5 harvest time is 20.10, the 6 harvest time is 30.10, the 7 harvest time is 10.11, the 8 harvest time is 20.11.

The sugar content of root crops was determined by cold digestion with a saccharimeter-polarimeter. To determine alpha-amino nitrogen, the method of Steenek and Pavlas, modified by Vininger and Kubadin was used which is based on measuring the optical density with a spectrophotometer. The content of potassium and sodium was determined by the method of Silin on a flame photometer. The standard sugar losses in the molasses formation were calculated according to the Braunschweig formula, derived by Buchholz *et al*. (1995). The content of refined sugar was calculated as the difference between the sugar content and the standard sugar losses in molasses. Gross output of sugar was defined as a product of yield and sugar content and gross output of refined sugar was calculated as a product of yield and content of refined sugar.

RESULTS AND DISCUSSION

The results of studies on the accumulation of the aboveground mass of sugar beet plants showed that every day of delayed harvesting leads to a reduction in the weight of the foliage without forming new leaves.

On average for3 years of research the maximum death of leaves comes at the end of September beginning of October (Fig. 1). The least decrease in the tops is observed at the 1st and control dates of harvesting as at this stage the photosynthesis productivity of the leaf apparatus is higher than in the subsequent harvesting

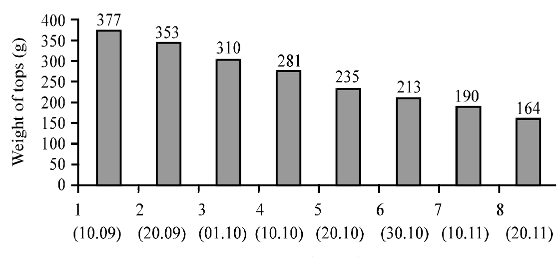

Fig. 1: Dynamics of accumulation of plant overground weight (g) (2015-2017)

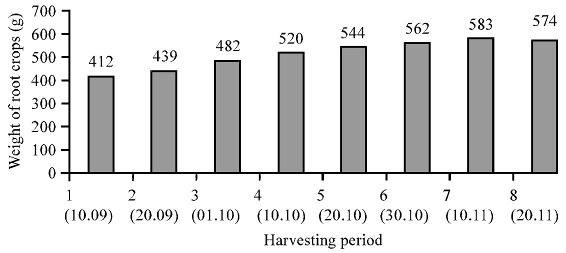

Fig. 2: Dynamics of accumulation of root crops, g (2015-2017)

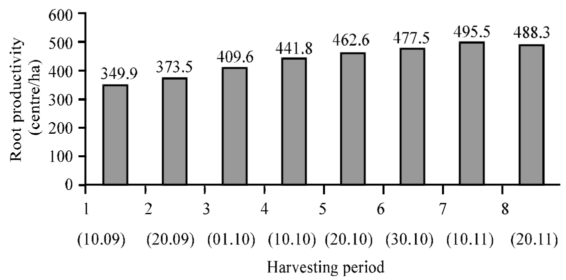

Fig. 3: Root productivity, centner/ha (2015-2017)

periods. Experiments carried out by Islamgulov and Bakirova (2017b) showed a similar dependence of changes in the above-ground mass of sugar beet plants on the harvesting period.

The dynamics of mass accumulation of root crops during the years of research shows that the intensive growth of sugar beet roots falls on the 3rd and 4th harvesting periods and with further harvesting periods, the growth rate is less intensive (Fig. 2). After November 20 (th 8th term of harvesting), there is a decrease in this indicator which apparently is related to the final phase of the life activity of the represented culture. Morozov *et al*. (2016) argue that the reduction in the mass of root crops is associated with the biological minimum of air and soil temperature.

The studied options for the timing of sugar beet harvesting differed in the yield of root crops. On average, this indicator had an increase from the 1st to the 7th harvesting terms in 3 years and on the 8th there was a slight decrease. The maximum increase was observed from the second to the 4th harvesting period during all the years of research. Consequently, the yield of sugar beet is dependent on the timing of its harvesting (Fig. 3). A correlation analysis of the experimental data for 3 years showed that there is a strong, positive relationship between the harvesting period and the yield of sugar beet roots. The correlation index (η) is equal to 0.85.

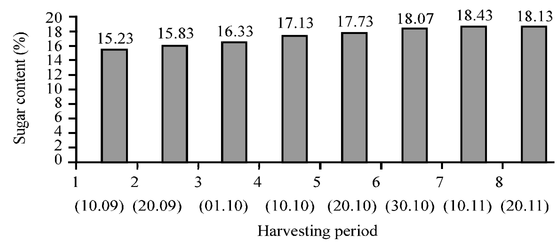

Fig. 4: Sugar content (%) (2015-2017)

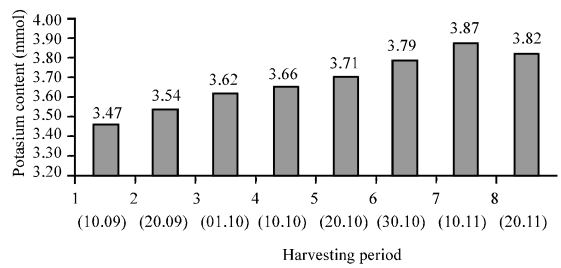

Fig. 5: Potassium content in root crops, mmol (2015-2017)

The sugar content of root crops within 3 years of research naturally increases and by November 10 it reached its maximum value. On the 8th period of harvesting, an insignificant decrease in sugar content is observed (an average of 0.30%). Reduction of sugar content is apparently associated with a decrease in the intensity of growth processes due to a decrease in air temperature and the use of sugar for respiration (Fig. 4).

The most intensive sugar formation on average in 3 years falls on the 3rd and 4th terms of harvesting in other cases, the accumulation of sugar occurred without sudden jumps. Between the time of harvesting and the sugar content in the sugar beet root crops, there is a very strong positive relationship. The correlation index (η) is equal to 0.94. The content of potassium in sugar beet root crops changed during3 years of testing (Fig. 5). So the greatest content of potassium was in 2016 (4.01 mmol) the 7th harvesting period, the smallest in 2017 (3.18 mmol) the 1st harvesting period. In other cases, the increase in potassium was not significant. The correlation index (η) between these two indicators is equal to 0.48, the connection is weak.

Unlike potassium, the sodium content decreased from the 1st-7th harvesting period. On average for 3 years from the 1st-6th harvesting time (October 30) fell from 0.93-0.77 mmol (by 17.2%). On November 10, the sodium content increased to 0.80 mmol, followed to 0.80 mmol,

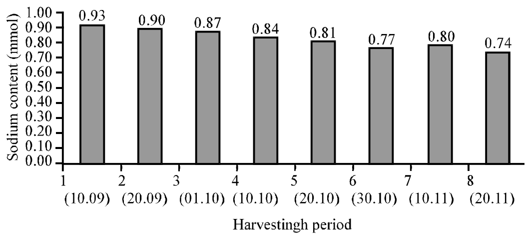

Fig. 6: Sodium content in root crops, mmol (2015-2017)

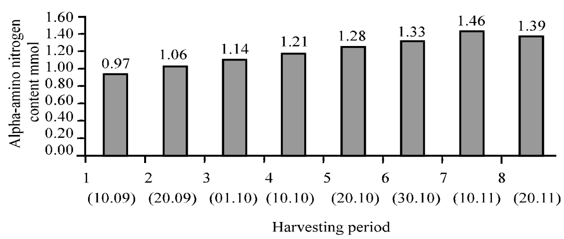

Fig. 7: Alpha-amino nitrogen content in root crops (mmol) (2015-2017)

followed by a decrease to 0.74 (November 20) (Fig. 6). The greatest decrease in the content of sodium accounted for the 4th and 5th periods of harvesting. The relationship between these indicators is inverse, moderate. The correlation index (η) is equal to 0.59.

The pattern of changes in the alpha-amino nitrogen content was similar to the change in the potassium content. The increase in its content occurred before November 10 (0.97-1.46 mmol). In contrast to the potassium content, the alpha-amino nitrogen content increased by 50.5%. Between the 7th and 8th harvesting periods, there was also a slight decrease of 4.8% to 1.39 mmol. The maximum value of alpha-amino nitrogen content was observed in 2015-1.71 mmol (November 10). On average for 3 years of research, the smallest increase in alpha-amino nitrogen was observed at the 3rd and 4th harvesting periods (Fig. 7). Correlation analysis showed that between the time of harvesting and the content of alpha-amino nitrogen in sugar beet roots, there is a moderate, positive relationship. The correlation index (η) is equal to 0.62.

The sugar loss varied from 1.20-1.46%. In 2015, standard sugar losses varied from 1.27% (the 1st harvesting period) to 1.46% (the 7th harvesting period) in 2016 from 1.25-1.37% and in 2017 from 1.20-1.35%. The increase in standard losses in molasses at later harvesting times was associated with an increase in potassium and alpha-amino nitrogen (Fig. 8). On average for 2015 and 2017 sugar losses

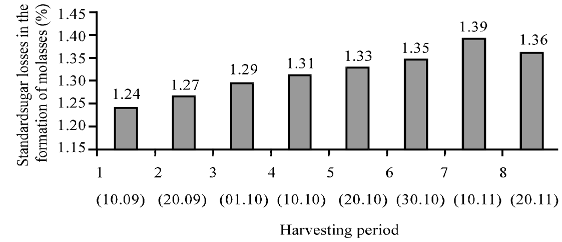

Fig. 8: Standard sugar losses (SSL) in the formation of molasses (%) (2015-2017)

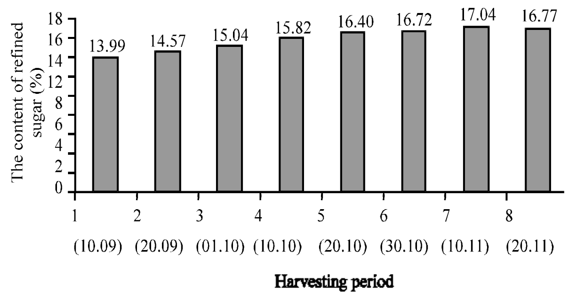

Fig. 9: The content of refined sugar (CRS) in root crops (%) (2015-2017)

between the 3rd and 6th harvesting periods were minimal, compared to the remaining harvesting periods. The relationship between these indicators is moderate, positive. The correlation index (η) is equal to 0.65.

The variance analysis of the experimental data for 3 years showed that the studied variants significantly exceeded the control (the second harvesting period) for yields, sugar content and the content of molasses-forming substances in the beet roots. The actual difference (deviation from control) in all cases exceeded the value of HCP_{05}.

The amount of purified sugar content also depended on the timing of harvesting. The greatest content was observed in 2017, on the 7th harvesting period and amounted to 17.55%, the smallest in 2016 the 1st harvesting period (13.85%). On average for 3 years there is an increase in the value of this indicator from the 1st to the last date of harvesting. The maximum increase (0.79%) was between the 3rd and 4th terms of harvesting in 2016. Between the 7th and 8th harvesting periods, the content of refined sugar decreased (Fig. 9). For 2015-2017 years the increase in the content of refined sugar accounted for the 4th time of harvest. Late harvesting times provided the greatest amount of refined sugar. Between these indicators there is a positive, very strong relationship. The correlation index (η) is equal to 0.93.

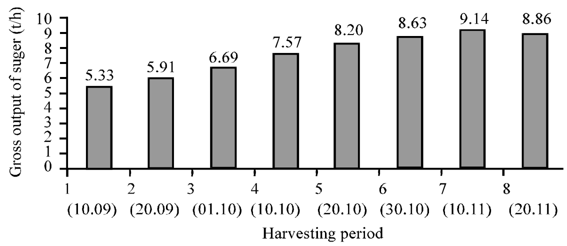

Fig. 10: Gross output of sugar (GOS), t/ha (2015-2017)

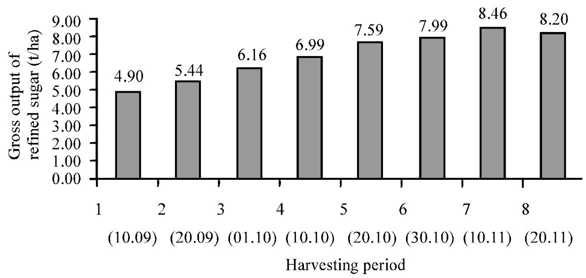

Fig. 11: Gross output of refined sugar (GORS), t/ha (2015-2017)

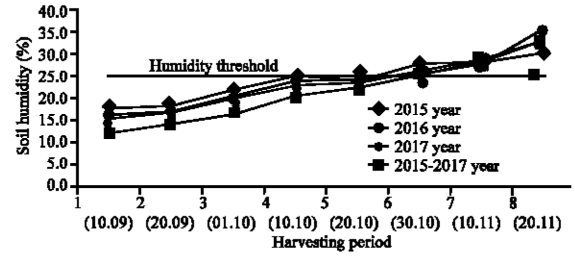

Fig. 12: Soil humidity at the depth of the arable layer (%) (2015-2017)

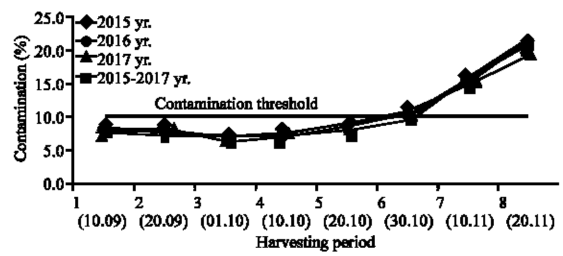

Fig. 13: Contamination of sugar beet root crops during the harvesting period (%) (2015-2017)

Gross output of sugar in 2015 varied depending on the harvesting period from 4.98 t/ha (the 1st harvesting period) to 8.43 t/ha (the 7th harvesting period). In 2016, the harvest of sugar was higher and amounted to 5.17-8.79 t/ha. The value of this indicator in 2017 was the largest and varied from 5.85-10.21 t/ha. Between the 7th and 8th harvesting periods, sugar harvest was reduced due to a decrease in the sugar content in the root crops (Fig. 10). On average for 3 years, the highest value of this indicator was in later harvesting periods 9.14 t/ha (the 7th harvesting period), the intensity of the increase between terms was maximum at the 3rd and 4th harvesting periods (0.77-0.88). Between these indicators there is a strong, positive relationship. The correlation index (η) is equal to 0.90.

On average in 3 years, the greatest value of the gross output of refined sugar was at a later harvesting time-8.46 t/ha (the 7th harvesting period), the smallest in the early harvesting period-4.90 t/ha (the 1st harvesting period). Higher indicators in this direction distinguished in 2017 when the maximum value was reached-9.48 t/ha (Fig. 11). From the average fig. for3 years it can be seen that a high increase was obtained on the 4th term of arvesting (October 10)-0.83 t/ha. Between the time of harvesting and the gross output of refined sugar there is a strong, positive connection. The correlation index (η) is equal to 0.90.

Scientists Ismagilov and Islamgulov (2016) propose an analysis between regressors and criterial variables, since this makes it possible to predict the values of the dependent variable from the independent variable.

The main causes of root crop losses when taken at the sugar factory are contamination and freezing. The high contamination of sugar beet roots in later periods is primarily due to the amount of precipitation in a given period that affects the increase in soil moisture in the plow layer. In turn, the percentage of contamination of root crops depends on soil moisture.

The soil moisture content at the depth of the arable layer averaged from 15.5-33.1% during the years of research, from the 1st to the 3rd harvesting period this indicator is below the norm. From the 4th to the 5th harvesting time, the soil moisture content is within the norm. At the 6th term, the soil moisture in the plow layer is slightly below the optimum value for sugar beet. Already on the 7th and 8th terms, soil moisture is much higher than in the previous harvesting periods (Fig. 12).

Contamination of sugar beet root crops on average for 2015-2017 has reached 20.8%. A reduced percentage of contamination falls on the 3rd harvesting period. For the 1st two terms, the pollution factor is between 7.7 and 8.5%. From the 4th to the 8th harvesting period it increases with a sharp rise to the 8th harvesting period (Fig. 13). The high contamination of sugar beet in root crops in later periods is associated with

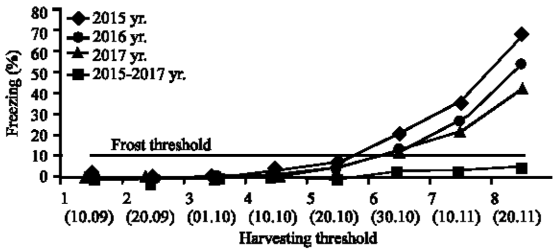

Fig. 14: Freezing of sugar beet root crops during the harvesting period (%) (2015-2017)

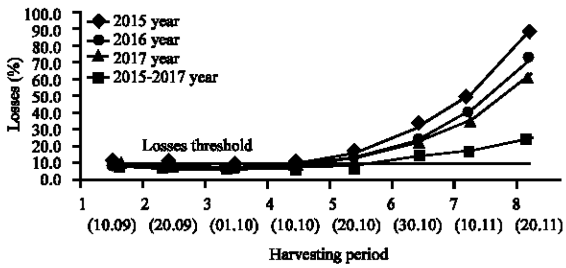

Fig. 15: Losses of sugar beet root crops during the harvesting period (%) (2015-2017)

the amount of precipitation in a given harvesting period which affects the increase in soil moisture in the plow layer.

The freezing of sugar beet root crops in 2015 was fixed at the 6th harvesting period-2.4%, further options vary from 2.4-3.7%. In 2016, frostbitten root crops from 5th-8th harvesting periods varied from 4.3-53.4%, the sharpest increase occurred in the 8th harvesting period. In 2017, freezing is observed already at the 4th harvesting time-3.1% and by the 8th period it increases to 67.8% (Fig. 14). An increase in the percentage of frostbitten beet roots is primarily due to temperature conditions. According to the data it is on the 8th term that there is a sharp drop in air temperature, respectively and soil cover. According to the data it is on the 8th term there is a sharp decrease in air temperature and respectively in soil cover.

Figure 15 presents data on losses due to contamination and freezing of root crops in total. The value of this indicator rises sharply in the November harvesting period. From the 1st-4th time of harvesting, the number of losses is not so great in contrast to the subsequent harvesting periods. The maximum percentage of losses (89.9%) was observed at the 8th time of harvesting in the 3rd year of research. The smallest losses on average for 3 years fall on the 3rd term of harvesting.

So on average for 2015-2017 years the highest yield was recorded at the 5th harvesting period (October 20), slightly lower at the 4th term. And with the 8th harvest,

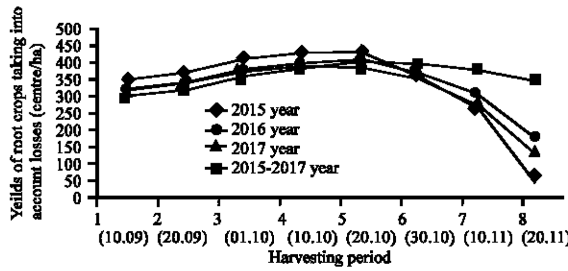

Fig. 16: Yields of sugar beet root crops at different harvesting times, taking into account losses due to contamination and freezing, centner/ha (2015-2017)

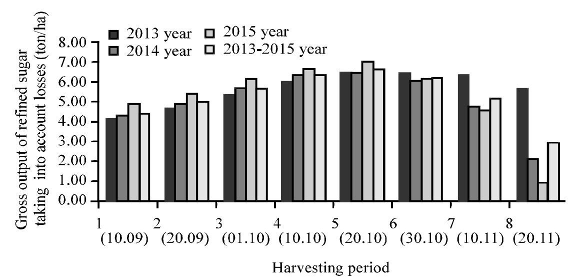

Fig. 17: Gross Output of Refined Sugar (GORSL) taking into account losses (2015-2017)

the yield of root crops was minimal and amounted to 183.4 (Fig. 16). On average, over 3 years of research, the maximum gross output of refined sugars, taking into account losses was identified at the 5th harvesting period (6.66 t/ha), slightly lower for the 4th and 6th harvesting periods (6.40 and 6.22 t/ha). The minimum value of this indicator was at the 7th harvesting period (2.93 t/ha) due to large losses caused by contamination and freezing of root crops (Fig. 17).

The gross yield of sugar and the gross output of refined sugar increased from the 1st to the 7th harvesting period. Gross output of refined sugar, taking into account losses in contrast to previous indicators increases from the 1st to the 5th harvesting periods in the 6th there is a slight decrease and on the 7th and 8th terms a sharp decline (Fig. 18). Reduction is associated with high losses during harvesting. This drawing gives an opportunity to choose the most optimal harvesting time for obtaining the maximum harvest with high technological qualities. In order to obtain the maximum gross output of refined sugar, taking into account the intensity of the increase or decrease in the indicators that directly affect the yield of sugar, contamination and freezing of root crops, the optimal for the harvesting of sugar beets is the period from 10-25 October.

In the studies by Bloch and Hoffmann (2003), the later periods are optimal for harvesting sugar beets. The

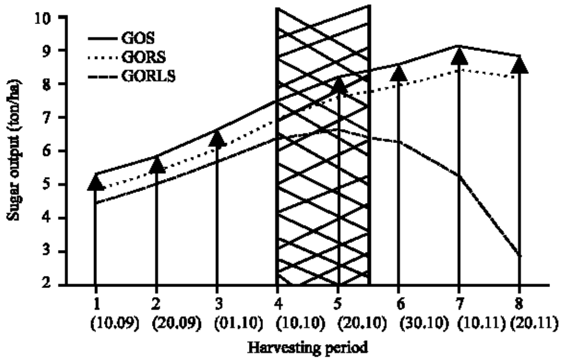

Fig. 18: Sugar output, ton/ha (2015-2017)

shift in the harvesting schedule for a later period is related in our opinion, to the milder soil and climatic conditions of Germany where these experiments were carried out.

An analysis of economic efficiency has shown that the profitability of sugar beet production in calculations for 3 different indicators (gross sugar harvest, gross output of refined sugar, gross output of refined sugar taking into account losses) is not the same. The highest level of profitability on gross sugar harvest was at the 7th harvesting period-459%, the gross output of refined sugar-418% (the 7th harvesting period), the lowest for harvesting in the 1st term (228 and 202%, respectively). The highest profitability for the gross output of refined sugar, taking into account losses due to contamination and freezing of root crops was the 5th term of harvesting-308%, the smallest with the 8th term of harvesting (79%). To assess the productivity of sugar beet, it is more correct to use the gross output of refined sugar, taking into account losses due to contamination and freezing of root crops, than gross output of sugar. The calculation of the economic efficiency of cultivation taking into account the contamination and freezing of root crops is more appropriate for the conditions of the southern forest-steppe of the Republic of Bashkortostan.

The calculation of the economic efficiency of sugar beet growing through the gross output of refined sugar, taking into account losses due to contamination and freezing of root crops, showed that the optimal harvesting period in the natural conditions of the Southern forest-steppe of the Republic of Bashkortostan is from 10-25 October.

The results obtained in the course of the study make it possible to recommend to the sugar plants of the Republic of Bashkortostan in addition to the mass and sugar content of the root crops, the content of the molasses (potassium, sodium and alpha-amino nitrogen) in sugar beet root crops in order to more accurately assess the quality of the raw materials and calculate them with commodity producers.

CONCLUSION

In conditions of the southern forest-steppe of the Republic of Bashkortostan, plants of the sugar beet hybrid RMS-120 began to die off intensively in late September early October. The weight of sugar beet root crops increased until the end of October (before the 7th harvesting period inclusive). The most intensive growth of sugar beet root was observed in the period from the 3rd-4th harvesting period in the subsequent the growth rate was significantly reduced.

The yield of sugar beet root crops increased (by 41.6%) until the end of October (before the 7th harvesting period) (correlation index $\eta = 0.85$). The sugar content of the root crops increased until the tenth of November, although, a slight decrease was observed in early November ($\eta = 0.94$).

In order to determine the optimal time for harvesting sugar beet, along with the yield, the technological qualities of root crops (the content of sugar, potassium, sodium and alpha-amino nitrogen in root crops) are important.

The content of potassium in root crops increased from the 1st-7th harvesting period ($\eta = 0.48$). The sodium content on the contrary, decreased from the 1st to the 8th harvesting period ($\eta = 0.59$). There is a significant increase in the content of alpha-amino nitrogen in root crops (by 50.5%) from the 1st-7th harvesting period ($\eta = 0.62$).

In the late harvesting periods (the 7th and 8th), sugar losses increase sharply, during the period from the 3rd to the 6th harvesting period, the losses were minimal ($\eta = 0.65$). There was an increase in the content of refined sugar from the 1st-7th harvesting period and by the 8th harvesting period, there was a slight decrease in the content of refined sugar in root crops ($\eta = 0.93$).

A natural increase in the gross output of refined sugar occurred from the 1st-7th time of harvesting in the 8th period there was a slight decrease ($\eta = 0.90$).

Contamination and freezing of root crops are important indicators in determining the optimal time for harvesting sugar beet. Since, the 5th harvesting period due to the increase in soil moisture, the contamination of the sugar beet root crops has increased and amounted to 89.9% during harvesting in the 8th period. Damage to root crops by frost occurred from October 10 and maximum freezing was during harvesting in the 8th period. Loss of root crops due to contamination and freezing increased sharply, starting from the 6th harvesting period. The highest yield of root crops and the gross output of refined sugar, taking into account losses, amounted to the 5th term of harvesting.

The greatest profitability of cultivation of sugar beet in the southern forest-steppe of the Republic of

Bashkortostan for of sugar and for the gross output of refined sugar was during the 7th harvest (459 and 418% respectively), the lowest for harvesting in the 1st term (228 and 202%, respectively). The profitability of the gross output of refined sugar including losses was the highest at the 5th harvest period (308%) and the lowest at the 8th harvest period (79 %). For an objective assessment of the economic efficiency of sugar beet cultivation, it is more appropriate to use the gross output of refined sugar for calculating the level of profitability, taking into account losses due to contamination and freezing of root crops, than gross output of sugar.

According to the set of indicators (yield, sugar content and molasses-forming substances in root crops, contamination and freezing of root crops), the optimal time for harvesting sugar beet in the natural conditions of the Southern forest-steppe of the Republic of Bashkortostan, using modern beet harvesters is the period from 10-25 October.

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