

Formation of the balance of nutrients in sugar beet crops depending on fertilization and crop rotation structure

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Purpose. To investigate the influence of organic-mineral fertilization systems and the structure of crop rotations on the use and balance of nutrients in the agrocenosis of sugar beet. **Methods.** Long-term field and analytical. **Results.** Research data on nutrient removal by sugar beet and their balance in the soil with the use of organic-mineral fertilization systems in short grain-beet crop rotations are given. It has been established that alternative organic-mineral fertilization systems in conditions of sufficient moisture on leached chernozem are able to form stable bases for growing sugar beet only under the condition when the sugar beet leaves are left on the field. In the case of alienation leaves from the field, sustainable cultivation of sugar beet can be formed only by a traditional manure-based fertilization system. **Conclusions.** The application of mineral fertilizers under sugar beet in a dose of N90P90K90 ensured the yield of roots in crop rotations of 60.4-63.0 t/ha with total removal of nitrogen - 174-185 kg/ha, phosphorus - 44-48, potassium - 199-214 kg/ha. The mineral fertilization system was accompanied by a shortage of nutrients in the soil, nitrogen and potassium prevailed in the removal of nutrients with the ratio N:P:K = 3.0-4.0:1:4.4-4.5. By leaving leaves on the field, alternative organic-mineral fertilization systems with the application of straw or a combination of straw and green mass of white mustard on the background of N90P90K90 formed a balanced balance of nutrients in the soil with a slight deficiency of nitrogen and potassium at the intensity of nitrogen balance 88-95%, phosphorus - 275 -319%, potassium - 90-102%. In the case of removal of leaves from the field, the mentioned fertilization systems were ecologically unstable in terms of nitrogen and potassium and were accompanied by the intensity of nitrogen balance - 55-56%, phosphorus - 182-198%, potassium - 56-57%. The crop rotation factor did not have a significant impact on the formation of indicators of the balance of nutrients in the soil. A positive balance of nutrients was achieved with a traditional manure-based organic-mineral fertilization system. High amounts of nutrients in the manure formed a reliable foundation for extended reproduction of leached chernozem fertility and increased the fund of mobile forms of nutrients in the soil. With the application of N90P90K90 + 30 t/ha of manure and leaving the leaves in the field, the intensity of nitrogen balance was 175-180%, phosphorus - 458-485%, potassium - 179-184%; for the alienation of the leaves from the field - 114-117%, 311-330% and 111-114%.

Keywords: *sugar beet, nutrients, balance.*

Introduction. In the conditions of increasing warming, obtaining stable yields of agricultural crops depends significantly on the stabilization or extended reproduction of soil fertility [1], [2]. A balanced balance of nutrients in the soil is the

basis for stabilization of soil formation processes, preservation of soil fertility and provision of stable foundations for the cultivation of agricultural crops [3], [4].

In conditions of an acute shortage of manure, stabilization of the balance of organic matter and nutrients in the soil is facilitated by the use of alternative fertilization systems with the introduction of by-products and green manure [5], [6]. These fertilization systems provide for the removal of nutrients from the soil only by the marketable crop, which allows to reduce the removal of nutrients from the field by 30–45% [7]. Leaving by-products on the field attracts nutrients to the recirculation processes and creates a regime of more comfortable mineral nutrition of the following crops in the crop rotation [8], [9], [10].

The study of balance issues is the basis for optimizing the doses of mineral fertilisers, the formation of stable principles of production, and therefore it is timely and requires constant monitoring [11].

The purpose of the research was to investigate the influence of organic-mineral fertilisation systems and the structure of crop rotations on the use and balance of nutrients in the agrocenosis of sugar beet.

Research materials and methods. The research was conducted in sugar beet crops during 2019-2022 in a long-term stationary field experiment of the Uladovo-Lyulynetsk research and selection station of the IBC&SB. The area of the sowing plot was 200 m², the accounting area was 100 m². Placement of options in experiments is systematic and sequential, repeated three times.

The soil of the experimental field was leached chernozem with the following agrochemical and physicochemical properties of the 0-30 cm layer: pH_{KCl} - 6.1-6.2, hydrolytic acidity by Kappen - 1.14-1.30 mg-equiv./100 g of soil, organic matter content by Tyurin – 4.0-4.2%, alkaline hydrolyzed nitrogen – 120-127 mg/kg of soil, mobile phosphorus and potassium by Chirikov - 158-170 and 66-84 mg/kg of soil.

The sugar beet hybrid “Boruta” German origination was sown at the experiment. Mineral fertilizers were applied in autumn under plowing in the forms of ammonium nitrate, simple granulated superphosphate and potassium chloride.

Sugar beet was grown under Ukrainian intensive technology that was recommended for the forest-steppe zone.

Harvesting and recording of the yield was carried out by the method of trial plots, followed by weighing and conversion to an area of 1 ha. The content of nutrients in plant samples was determined after wet ashing according to Ginzburg: nitrogen - by Kjeldahl according to DSTU 7169-2010, phosphorus - according to DSTU ISO 6491:2004, potassium - using a flame photometer.

A calculation method was used to determine the removal and balance of nutrients in the agrocenosis of sugar beet. The calculation of the balance was carried out under the removal of the straw from the field and under the conditions when the straw was left on the field.

Research results and their discussion. Studies have shown that with the application of mineral fertilisers in the dose of N90P90K90, the yield of roots in crop rotations on average for 2019-2022 was 60.4-63.0 t/ha, and of leaves - 19.7-24.1 t/ha, while with roots the sugar beet removed of the nitrogen of 112-120 kg/ha, phosphorus - 30-32, potassium - 122-131; with leaves of 59-65, 14-16 and 74-83 kg/ha. The removal of nitrogen by biological yield was 174-185 kg/ha, phosphorus - 44-48, potassium - 199-214 kg/ha. With the harvest of roots, sugar beet took nutrients from the soil 1.7-2.2 times more than with the harvest of leaf mass. The highest biological removal of nutrients was observed in the barley-peas-winter wheat-sugar beet crop rotation: nitrogen - 185 kg/ha, phosphorus - 48, potassium - 214 kg/ha, while in crop rotations with two fields of soybeans and with the predecessors of peas-oats removal of nitrogen was lower - by 9-11 kg/ha, phosphorus - by 3-4, potassium - by 12-15 kg/ha. Potassium and nitrogen prevailed in the biological removal of nutrients for the ratio N:P:K = 3.0-4.0:1:4.4-4.5 (Table 1).

Table 1.

Removal of nutrients by sugar beet depending on fertilisation and crop rotation structure, ULDSS, 2019-2022, kg/ha

No. var	Crop rotations (factor A)	Application of fertilisers under sugar beet (factor B)	Yield of roots, t/ha	Removal by roots			Yield of leaves, t/ha	Removal by leaves		
				N	P	K		N	P	K
1	Soybean-soybean-winter wheat-sugar beet	N90P90K90 - Fond	61,5	117	30	128	19,7	59	14	74
2		Fond + straw	65,8	124	32	138	22,3	67	16	85
3		Fond + straw + green manure	69,2	134	35	148	23,4	71	17	90
4		Fond + 30 t/ha of manure	69,4	134	34	147	23,6	71	16	89
5	Barley-peas-winter wheat-sugar beet	N90P90K90 - Fond	63,0	120	32	131	21,9	65	16	83
6		Fond + straw	64,9	122	31	138	23,2	69	16	88
7		Fond + straw + green manure	70,9	136	36	151	23,8	72	17	91
8		Fond + 30 t/ha of manure	69,6	137	36	151	24,1	73	17	93
9	Peas-vetch-oats-winter wheat-sugar beet	N90P90K90 - Fond	60,4	112	30	122	20,6	62	15	77
10		Fond + straw	64,3	120	33	134	22,0	66	16	84
11		Fond + straw + green manure	68,5	129	33	147	23,9	73	17	92
12		Fond + 30 t/ha of manure	69,7	133	35	149	24,6	74	18	95
LSD 05 (factor A)			1,3			0,6				
LSD 05 (factor B)			2,8			0,9				
LSD 05 (factor A+B)			3,9			1,5				

The addition of winter wheat straw to the mineral fertilisation system increased the yield of roots by 3.9-4.9 t/ha, leaves - by 1.4-2.6 t/ha, and increased the removal of nitrogen by the biological yield - by 6-15 kg/ha, phosphorus - by 4, potassium - by 12-21 kg/ha. A slight increase in potassium removal was observed in the crop rotation with two fields of soybeans, nitrogen - under the predecessors of peas-vetch-oats.

The use of N90P90K90 + straw + green manure contributed to the increase in the biological yield of sugar beet in conditions of sufficient moisture on leached chernozem: the yield of roots compared to the application of N90P90K90 increased - by 7.7-8.1 t/ha, of leaves - by 1.9-3.7 t/ha. Compared to the background of mineral fertilisers, the specified fertilisation system increased the removal of nitrogen by sugar beet in crop rotations - by 23-28 kg/ha, phosphorus - by 5-8, potassium - by 36-40 kg/ha.

The effect of the traditional manure-based fertilisation system on the biological productivity of sugar beet and removal of nutrients from the soil was similar to the alternative fertilisation with the application of mineral fertilisers, straw and green manure of white mustard. When applying N90P90K90 + 30 t/ha of manure, the yield of roots compared to the background of mineral fertilisers increased by 6.6-9.3 t/ha, leaves by 2.2-4.0 t/ha. At the same time, the removal of nitrogen by sugar beet in crop rotations increased by 25-33 kg/ha, phosphorus by 5-8, potassium by 30-45 kg/ha.

The calculation of the balance of nutrients showed that in the case of leaving sugar beet leaves on the field, the application of N90P90K90 formed a negative nitrogen balance in the amount of -27 kg/ha, potassium - -38 kg/ha, while the phosphorus balance was positive - 60 kg/ha. The removal of leaves from the field increased the deficit of nitrogen in the soil - by 3.2 times, potassium - by 2.9 times, and maintained a positive balance of phosphorus (Table 2).

The use of an alternative organic-mineral fertilisation system with the application of winter wheat straw under the condition that sugar beet leaves were left on the field formed a sustainable conditions for the cultivation of this crop in

conditions of sufficient moisture on leached chernozem. For the application of N90P90K90 + winter wheat straw, in the case of leaving leaves on the field, the balance of nitrogen in the crop rotation with two soybean fields was -10 kg/ha, phosphorus - 67, potassium - -2; with the predecessors of barley-peas – -8, 68 and -2, pea-vetch-oats predecessors – -6, 66 and 2 kg/ha. The specified fertilization system maintained a slight deficit of nitrogen in the soil in the amount of -6-10 kg/ha and potassium - -2 at the intensity of nitrogen balance in crop rotations - 92-95%, phosphorus - 300-319%, potassium - 99-102%. In the case of alienation of leaves from the field, a high deficit of nitrogen and potassium was formed in the soil in the amount of -72-77 and -82-90 kg/ha at the intensity of nitrogen balance in crop rotations - 60-61%, phosphorus - 202-211%, potassium - 69 -62%. The crop rotation factor had no significant influence on the formation of the balance of nutrients in the soil.

Table 2.

Balance of nutrients in the agrocenosis of sugar beet depending on fertilisation and crop rotation structure, ULDSS, 2019-2022

No. var	Crop rotations (factor A)	Application of fertilisers under sugar beet (factor B)	Balance, kg/ha		
			N	P	K
1	Soybean-soybean-winter wheat-sugar beet	N90P90K90 - Fond	<u>-27</u>	<u>60</u>	<u>-38</u>
			-86	46	-112
2		Fond + straw	<u>-10</u>	<u>67</u>	<u>-2</u>
			-77	51	-87
3		Fond + straw + green manure	<u>-20</u>	<u>64</u>	<u>-12</u>
				-91	47
4		Fond + 30 t/ha of manure	<u>106</u>	<u>131</u>	<u>123</u>
			35	115	34
5	Barley-peas-winter wheat-sugar beet	N90P90K90 - Fond	<u>-30</u>	<u>58</u>	<u>-41</u>
				-95	42
6		Fond + straw	<u>-8</u>	<u>68</u>	<u>-2</u>
			-77	52	-90
7		Fond + straw + green manure	<u>-22</u>	<u>63</u>	<u>-15</u>
				-94	46
8		Fond + 30 t/ha of manure	<u>103</u>	<u>129</u>	<u>119</u>
			30	112	26
9	Peas-vetch-oats-winter wheat-sugar beet	N90P90K90 - Fond	<u>-22</u>	<u>60</u>	<u>-32</u>
				-84	45
10		Fond + straw	<u>-6</u>	<u>66</u>	<u>2</u>
			-72	50	-82

11		Fond + straw + green manure	<u>-15</u> -88	<u>66</u> 49	<u>-11</u> -103
12		Fond + 30 t/ha of manure	<u>107</u> 33	<u>130</u> 112	<u>121</u> 26

Sustainable bases for growing sugar beet with a slight deficiency of nitrogen and potassium in the soil were created when using an alternative organic-mineral fertiliser system enriched in the organic component. With the application of N90P90K90 + straw + green manure, the balance of nitrogen in the soil in the case when the leaves was left on the field in a crop rotation with two soybean fields was -20 kg/ha, phosphorus - 64, potassium - -12; with the predecessors of barley-pea – -22, 63 and -15, of pea-vetch-oats – -15, 66 and -11 kg/ha. At the same time, the intensity of nitrogen balance in the soil was 83-88%, phosphorus - 275-300%, potassium - 90-93%. In the case of alienation of leaves from the field, the intensity of nitrogen balance in crop rotations decreased to 55-56%, phosphorus - to 182-198%, potassium - to 56-57%. The influence of the structure of short-rotational crop rotations on the formation of the balance of nutrients in the soil is determined to be insignificant.

A high positive balance of nutrients in the soil in all crop rotations was formed under the traditional manure-based organic-mineral fertilisation system. With the application of N90P90K90 + 30 t/ha of manure and in the case when the leaves was left on the field, the intensity of nitrogen balance in the soil was 175-180%, phosphorus - 458-485%, potassium - 179-184%; for the alienation of the leaves from the field - 114-117%, 311-330% and 111-114%. High amounts of nutrients in the manure formed a reliable foundation for extended reproduction of leached chernozem fertility and increased the fund of mobile forms of nutrients in the soil.

Therefore, in conditions of sufficient moisture, the use of alternative organic-mineral fertiliser systems for sugar beet is able to form sustainable foundations for the cultivation of this crop, when the leaves was left on the field. Under conditions of acute shortage of manure, the mentioned fertilisation systems are effective for use in short-rotation grain-beet crop rotations. The crop rotation

factor did not have a significant impact on the formation of indicators of the balance of nutrients in the soil.

CONCLUSIONS

1. The use of N90P90K90 for sugar beet in conditions of sufficient moisture on leached chernozem ensured the yield of roots in crop rotations of 60.4-63.0 t/ha under biological removal of nitrogen - 174-185 kg/ha, phosphorus - 44-48, potassium - 199-214 kg/ha. The mineral fertiliser system created a negative balance of nutrients in the soil. Potassium and nitrogen prevailed in the removal of nutrients for the ratio N:P:K = 3.0-4.0:1:4.4-4.5.

2. The use of alternative organic-mineral fertilisation systems with the application of straw or a combination of straw and green mass of white mustard over the background of N90P90K90, when the leaves remained on the field, formed a slight deficiency of nitrogen and potassium in the soil and a high positive balance of phosphorus at a tension of the nitrogen balance of 88-95%, phosphorus - 275-319%, potassium - 90-102%. In the case of removal of leaves from the field, these fertilisation systems created a sharp deficit of nitrogen and potassium in the soil at the tension of the nitrogen balance - 55-56%, phosphorus - 182-198%, potassium - 56-57%. The crop rotation factor had no significant influence on the formation of indicators of the balance of nutrients in the soil.

3. A positive balance of nutrients in the soil was achieved with a traditional manure-based organic-mineral fertilisation system. High amounts of nutrients in the manure formed a reliable foundation for extended reproduction of leached chernozem fertility and increased the fund of mobile compounds of nutrients in the soil. With the application of N90P90K90 + 30 t/ha of manure and leaving the leaves in the field, the intensity of nitrogen balance was 175-180%, phosphorus - 458-485%, potassium - 179-184%; for the alienation of the leaves from the field - 114-117%, 311-330% and 111-114%.

References

1. Liu Y., Ma J., He W., Lei Q., Gao Q., He P. Temporal and spatial variation of potassium balance in agricultural land at national and regional levels in China. *PLoS One*. 2017. 12(9). 1–17. <https://doi.org/10.1371/journal.pone.0184156>
2. Lukowiak R., Grzebisz W., Sassenrath G.F. New insights into phosphorus management in agriculture – A crop rotation approach. *Science of The Total Environment*. 2016. V. 542. 15. 1062–1077. <https://doi.org/10.1016/j.scitotenv.2015.09.009>
3. Zaryshniak A.S., Balyuk S.A., Lisovyi M.V., Komarista A.V. Balanc humusu i pozhynykh rehovyn v gruntakh Ukrainy [Balance of humus and nutrients in soils of Ukraine]. *Bulletin of agrarian science*. 2012. 1. 28–32. [in Ukrainian].
4. Sassenrath G.F., Schneider J.M., Gaj R., Grzebisz W., Halloran J.M. Nitrogen balance as an indicator of environmental impact: toward sustainable agricultural production. *Agricultural Food System*. 2013. 28. 276–289. <https://doi.org/10.1017/S1742170512000166>
5. Saiko V.F. (2008). Naukovi osnovy zemlerobstva v kointeksti zmin klimatu [The scientific basis of agriculture in the context of climate change]. *Bulletin of agrarian science*. 2008. 11. 5–10. [in Ukrainian].
6. Martyniuk S., Piłkuła D., Koziel M. Soil properties and productivity in two long-term crop rotations differing with respect to organic matter management on an Albic Luvisol. *Scientific Report*. 2019. 9. 1878. <https://doi.org/10.1038/s41598-018-37087-4>
7. Tsvey Ya.P. Rodiuchist gruntiv i produktyvnist sivozmin [Soil fertility and crop rotation productivity] (monograph). Kyiv: Komprint. 2014. 416. [in Ukrainian].
8. Blesh J., Drinkwater L. E. The impact of nitrogen source and crop rotation on nitrogen mass balances in the Mississippi River Basin. *Ecological society of America*. 2013. V. 23. 5. 1017–1035. <https://doi.org/10.1890/12-0132.1>
9. Venkatesh M.S., Hazra K.K., Ghosh P.K., Khuswah B.L., Ganeshamurthy A.N., Ali M., Singh J. & Mathur R.S. Long-term effect of crop rotation and nutrient management on soil-plant nutrient cycling and nutrient budgeting in Indo-Gangetic plains of India. *Archives of Agronomy and Soil Science*. 2017. V. 63. 14. 2007–2022. <https://doi.org/10.1080/03650340.2017.1320392>
10. Lemke R.L., VandenBygaart A.J., Campbell C.A., Lafond G.P., Grant B. Crop residue removal and fertilizer N: effects on soil organic carbon in a long-term crop rotation experiment on a Udic Boroll. *Agriculture Ecosystem Environment*. 2010. 135. 42–51. <https://doi.org/10.1016/j.agee.2009.08.010>
11. Nosko B.S., Duda G.G. Pro naslidky agroekologichnogo monitoryngu na bazi bagatorichnykh doslidiv z dobryvamy [On the consequences of agroecological monitoring based on long-term experiments with fertilizers]. Abstracts of reports of the IV congress of soil scientists and agrochemists of Ukraine. Kharkiv, 1994. 6–7. [in Ukrainian].

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