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FARMING AND AMELIORATION

Sugar Beet Harvest Depending on Crop Rotation, Method of Basic Tillage, and Dose of Mineral and Organic Fertilizers

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Abstract—The regularities of the influence of crop rotations, methods of basic tillage, and doses of mineral and organic fertilizers on the yield of sugar beet were studied in a multifactorial field experiment established in 1987 in the Belgorod oblast on typical heavy loamy chernozem with a 5.18–5.32% humus content in the 0–30 cm layer and 52–58 and 95–105 mg/kg of mobile phosphorus and potassium (according to Machigin), respectively, pH_{salt} = 5.8–6.4. The experiment was based on a full factorial 3 × 3 × 3 × 3 scheme, which includes 81 variants. The experiment had three repetitions. The plot size was 4 × 30 m. The regression method was used to describe the action and interaction of factors. The use of a quadratic model showed a close relationship between the actual and calculated values at R = 0.94–1.00. The grain-grass row crop rotation with perennial grasses had an advantage in which the average harvest of sugar beet root crops without fertilizers was 19.0 t/ha, 17.0 t/ha in the grain row crop rotation and 15.7 t/ha in the grain fallow crop rotation with black fallow. The nonmoldboard tillage was mostly used. In the grain-grass row crop rotation, the introduction of $N_{180}P_{180}K_{180}$ increased the yield by 68.8–103.3%. The use of 80 t/ha of manure provided an increase in yield by 53.7–84.7%. In tilled crop rotations, yield increases from organic and mineral fertilizers were higher. In variants with double doses of mineral fertilizers, depending on tillage, the yield increased by 89.5–130.0%; with manure doses of 40 t/ha, the yield increased by 17.1–42.7%, 80 t/ha gave 86.8–109.3%. The maximum yield in the experiment (48.9 t/ha) was found in the crop rotation with black fallow and double doses of fertilizers against the background of plowing. The efficiency of mineral and organic fertilizers was higher when using deep tillage methods. The largest yield of sugar beet was found in the variants with the combined use of organic and mineral fertilizers.

Keywords: sugar beet (*Beta vulgaris*), long-term multifactorial field experiment, crop rotation, basic tillage, mineral fertilizers, organic fertilizers

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INTRODUCTION

The increase in sugar production remains one of the most urgent problems of the Russian agro-industrial complex. Sugar beet, whose share in the structure of sown areas in the Belgorod oblast is approximately 10%, is one of the leading crops in the region. This crop is demanding on soil conditions and the level of mineral nutrition. An increase in the production of sugar beet and the profitability of the industry is possible with the growth of its yields. Science-intensive environmentally friendly technologies for growing crops provide for the high-quality and timely implementation of a set of related activities, including the selection of the best predecessors, high-quality soil cultivation, the use of seeds of higher reproductions, and the use of mineral and organic fertilizers and pesticides [1–3].

The efficiency of sugar beet cultivation technologies depends on many factors [4, 5]. Therefore, an optimal environmentally friendly technology requires detailed scientific information on the effectiveness of its constituent elements. These questions have not been sufficiently explored.

The purposes of the research are to study the regularities of the influence of crop rotations, methods of basic tillage, and doses of mineral and organic fertilizers on the yield of sugar beet and describe their effect using mathematical models.

MATERIAL AND METHODS

A long-term multifactorial field experiment according to a full factorial scheme was established in the Belgorod Federal Research Center of the Russian Academy of Sciences in 1987. The results of accounting for the sugar beet yield in the fifth rotation of the crop rotation, which were processed by the regression analysis method, were used to achieve this goal.

The soil of the experimental plot is a typical medium-thick low-humus heavy loamy chernozem on

Table 1. Meteorological conditions over the years of research

Year	The sum of average daily air temperatures above +10°C during the growing season (April–September), °C	The amount of precipitation for the period with an air temperature above +10°C, mm	HTC
2008	2621.1	140.5	0.54
2009	3067.5	137.4	0.45
2010	3605.6	202.7	0.56
2011	3152.3	282.2	0.89
2012	3547.1	296.6	0.84
Average	3198.7	211.9	0.66

loess-like loam with 5.18–5.32% of humus, 52–58 mg/kg of mobile phosphorus, and 95–105 mg/kg of mobile potassium in a layer of 0–30 cm (according to Machigin), $pH_{salt} = 5.8–6.4$ [6].

All known field experiments on this topic were carried out according to schemes with a small number of variants. They do not provide the accumulation of the necessary information to optimize the technologies for cultivating agricultural crops, including sugar beet [7]. In the conditions of the Belgorod oblast, the questions posed in the field experiment were studied for the first time, based on the use of mathematical methods for planning an experiment on typical chernozem using a complete factorial scheme. Experimental data were obtained that made it possible to model the effect of mineral and organic fertilizers with different methods of basic tillage in crop rotations with different levels of saturation with row crops.

The complete factorial scheme 3 × 3 × 3 × 3 includes 81 variants. The number of repetitions in the experiment is three. The size of the plot is 4 × 30 m. The method of split plots with a systematic arrangement of variants within repetitions was used when laying the experiment.

The scheme of the experiment included studying the following variants:

1. crop rotation (factor A)—grain-grass row crops with a 20% share of tilled crops (winter wheat–sugar beet–barley + perennial grasses (sainfoin)–perennial grasses of the first year–perennial grasses of the second year); row-grain with a 40% share of row crops (winter wheat–sugar beet–barley–corn for silage–peas); grain fallow with a 60% share of row crops (winter wheat–sugar beet–corn for silage–corn for grain–black fallow);

2. basic tillage (factor B)—moldboard (plowing to a depth of 30–32 cm), moldboardless (tillage with a tool of the Paraplow type at 30–32 cm), minimal (tillage with a disc harrow at 12–14 cm);

3. organic fertilizers (factor C)—0, 40, 80 t/ha of semidecomposed bedding cattle manure once per rotation for sugar beet;

4. mineral fertilizers (factor D)—0, $N_{90}P_{90}K_{90}$, $N_{180}P_{180}K_{180}$ in the form of ammophoska containing $N_{16}P_{16}K_{16}$.

The technology of cultivation of sugar beet is generally accepted for the Central Chernozem region. The sugar beet variety Lgovskaya odnosemyannaya 52 was sown on winter wheat.

Statistical analysis of the experimental data was carried out using the regression method. The quantitative dependences of the yield on the doses of organic and mineral fertilizers were calculated using a model with integer and quadratic powers for organic (*Of*) and mineral (*Mf*) fertilizers and integer powers for their pair interactions was used:

$$Y = a_0 + a_1 Of + a_2 Of^2 + a_3 Mf + a_4 Mf^2 + a_5 (Of Mf),$$

where Y is the yield of sugar beet, t/ha; a_0 is a free term reflecting the value of this indicator without fertilizers; and a_1, a_2, a_3, etc. are coefficients reflecting the action of a particular factor and the interactions of factors.

Only the main effects of the factors and their pair interactions were used in the regression equation since they account for approximately 95% of the effects of yield increases [8].

The equations were calculated using experimental data in a program that provides for the sequential evaluation and exclusion of insignificant regression terms based on the Student's t-test at a probability level of 0.95 [9]. The consistency of theoretical and actual data was assessed using the coefficient of multiple correlations (R).

Meteorological observations were carried out at a specially equipped meteorological post located on the experimental site (Table 1). The sum of temperatures above +10°C in the agroclimatic zone of research is enough to form a sugar beet crop.

The HTC for the fifth rotation of the crop rotation (2008–2012) varied, on average, from 0.45 in 2009 to 0.89 in 2011 and was equal to an average of 0.66, which is significantly lower than the long-term average value (1.10) and characterizes the growing conditions as

Table 2. Regression equations reflecting the dependence of sugar beet yields on the doses of organic and mineral fertilizers in crop rotations with different methods of basic tillage

Year	Tillage	Regression equation	Correlation coefficient
		Grain-grass row crop rotation	
2008	plowing	$Y = 212.03 + 93.81Of + 130.34Mf$	0.975
	nonmoldboard	$Y = 306.51 + 47.40Of^2 + 43.66Mf^2$	0.991
	minimal	$Y = 227.92 + 80.14Of + 102.61Mf$	0.970
2009	plowing	$Y = 256.92 + 53.84Of^2 + 86.36Mf - 25.23OfMf$	0.981
	nonmoldboard	$Y = 237.52 + 54.67Of + 102.35Mf$	0.959
	minimal	$Y = 248.85 + 36.34Of^2 + 92.31Mf$	0.956
2010	plowing	$Y = 66.44 + 34.83Of + 45.18Mf$	0.965
	nonmoldboard	$Y = 88.24 + 22.83Of + 25.33Mf$	0.988
	minimal	$Y = 96.46 + 20.33Of + 25.72Mf$	0.960
2012	plowing	$Y = 171.47 + 31.38Of^2 + 103.22Mf$	0.972
	nonmoldboard	$Y = 187.71 + 23.87Of^2 + 67.06Mf + 14.83OfMf$	0.994
	минимальная	$Y = 178.67 + 70.67Of + 69.00Mf$	0.993
		Grain-fallow row crop rotation	
2008	plowing	$Y = 220.28 + 77.78Of + 104.88Mf$	0.987
	nonmoldboard	$Y = 240.41 + 81.98Of + 84.06Mf$	0.975
	minimal	$Y = 226.61 + 55.45Of + 89.42Mf$	0.961
2009	plowing	$Y = 164.78 + 144.11Of + 162.50Mf - 49.50OfMf$	0.986
	nonmoldboard	$Y = 158.32 + 132.42Of + 127.97Mf - 46.42OfMf$	0.976
	minimal	$Y = 209.24 + 83.33Of + 78.39Mf$	0.978
2010	plowing	$Y = 75.29 + 9.74Of^2 + 36.44Mf$	0.994
	nonmoldboard	$Y = 67.72 + 8.00Of^2 + 37.28Mf$	0.983
	minimal	$Y = 81.35 + 4.81Of^2 + 17.78Mf$	0.920
2012	plowing	$Y = 200.89 + 28.89Of + 21.28Of^2 + 35.44Mf + 15.17OfMf$	0.999
	nonmoldboard	$Y = 195.50 + 56.72Of + 61.56Mf$	0.948
	minimal	$Y = 203.78 + 51.83Of + 44.50Mf$	0.959
		Grain-fallow row crop rotation	
2008	plowing	$Y = 195.46 + 43.70Of + 10.25Of^2 + 105.92Mf - 15.74Mf^2 + 38.75OfMf$	1.000
	nonmoldboard	$Y = 184.75 + 47.68Of + 7.36Of^2 + 91.74Mf - 5.30Mf^2 + 29.70OfMf$	1.000
	minimal	$Y = 197.78 + 207.92Of - 56.59Of^2 + 108.60Mf$	0.994
2009	plowing	$Y = 163.46 + 97.82Of + 145.75Mf$	0.945
	nonmoldboard	$Y = 248.32 + 29.94Of^2 + 135.23Mf$	0.959
	минимальная	$Y = 193.40 + 48.54Of^2 + 94.31Mf$	0.977
2010	plowing	$Y = 54.47 + 39.14Of - 7.05Of^2 + 54.2Mf - 9.29Mf^2 - 3.31OfMf$	0.999
	nonmoldboard	$Y = 76.23 + 7.91Of^2 + 36.76Mf$	0.970
	minimal	$Y = 98.83 + 5.99Of^2 + 23.36Mf$	0.991
2012	plowing	$Y = 119.87 + 104.58Of + 93.48Mf$	0.960
	nonmoldboard	$Y = 183.07 + 25.61Of^2 + 106.69Mf - 25.02Mf^2 + 14.12OfMf$	0.996
	minimal	$Y = 166.06 + 62.99Of + 65.86Mf$	0.966

Table 3. Yield of sugar beet depending on the types of crop rotation and methods of tillage for the fifth rotation, t/ha

Type of crop rotation	Year				Average for rotation
	2008	2009	2010	2012	
Plowing					
Grain-grass row	21.2	25.7	6.6	17.2	17.7
Grain row	22.0	16.5	7.5	20.1	16.5
Grain-fallow row	19.6	16.4	5.5	12.0	13.3
Nonmoldboard tillage					
Grain-grass row	30.7	23.8	8.8	18.8	20.5
Grain row	24.0	15.8	6.8	19.6	16.6
Grain-fallow row	18.5	24.8	7.6	18.3	17.3
Minimal tillage					
Grain-grass row	22.8	24.9	9.7	17.9	18.8
Grain row	22.7	20.9	8.1	20.4	18.0
Grain-fallow row	19.8	19.3	9.9	16.6	16.4

arid. The most acute lack of moisture was observed in 2008, 2009, and 2010.

The water requirement of sugar beet during the growing season is 365–470 mm. In our studies, the amount of precipitation for the period with temperatures above +10°C on average for 2008–2012 was at the level of 211.9 mm, that is, two times less than the optimal value of this indicator. The water requirement of sugar beet during the growing season is not consistent. From June to August, during the greatest mass gain, it is at its highest. A sufficient amount of precipitation, which favorably affected the crop yield, fell during the years of research in the period of intensive plant growth and, as a result, in the period of the consumption of the maximum amount of moisture (May–July).

In July 2010, the average monthly temperature was 26.5°C, while the long-term norm was 19.9°C. The maximum air temperature this month was 38°C, and it reached 59°C on the soil surface, which negatively affected the yield of sugar beets. Therefore, in general, the study period turned out to be unfavorable for sugar beet, the yield of which was limited by insufficient rainfall.

RESULTS AND DISCUSSION

Earlier studies have shown that a half model is more suitable for describing the action and interactions of the studied factors on the yield of agricultural crops, their growth and development, and the content of nutrients in plants, and a quadratic model is more suitable for changing indicators characterizing the level of soil fertility. This conclusion was made based on the results of studies in which the experimental schemes included four gradations of the studied factors and more.

In our case, the scheme of the field experiment provides for a limited number of factor gradations (three), including control, and has a large "step width" between fertilizer doses. Such data were processed for the first time by the regression method using a quadratic model, which showed a high degree of correlation between the actual and calculated values of the sugar beet yield from 0.945 to 1.000 (Table 2). At the same time, the effect of such factors as organic and mineral fertilizers is shown in all regression equations. The influence of their paired interactions on the yield of sugar beet was proved for nine regression equations.

The yield of sugar beet, calculated according to the regression equations, changed over a wide range over the years of the fifth rotation (Table 3). It was the smallest in 2010, when the collection of root crops in the variants without fertilizers did not exceed 5.5–9.9 t/ha, which is associated with abnormally high temperatures in summer during the growing season. The highest yield was shown in 2008: 18.5–30.7 t/ha.

The grain-grass row crop rotation with perennial grasses, in which the average yield of sugar beet for treatments was 19.0 t/ha, had a noticeable advantage among the studied crop rotations. In the grain-row crop rotation, it was equal to 17.0 t/ha, while it was equal to 15.7 t/ha in the grain-fallow crop rotation with black fallow.

Among the main tillage methods, the nonmoldboard method had a significant advantage, using which the average yield for crop rotations was 18.1 t/ha. On average, the maximum yield of sugar beet against an unfertilized background for the fifth rotation was recorded in a grain-grass-rowed crop rotation for nonmoldboard tillage. It amounted to 20.5 t/ha.

The use of mineral and organic fertilizers contributed to a significant increase in the yield of sugar beets in all crop rotations (Table 4). In grain-grass-tillage crop rotations with perennial grasses, the introduction of azophoska at a dose of $N_{90}P_{90}K_{90}$ increased yield by 29.1–51.7% relative to the control. A dose of $N_{180}P_{180}K_{180}$ increased yield by 68.8–103.3%, while the largest yield was harvested in the variant with moldboard plowing. The use of manure in a single dose provided an increase in yield by 18.1–30.3% and a double dose increased yield by 53.7–84.7%. The largest yield of sugar beet was shown in the variants with the combined use of organic and mineral fertilizers. Increases, compared with variants without fertilizers, amounted to 129–173%.

The increase in yields with the use of organic and mineral fertilizers was noticeably higher in tilled crop rotations. Depending on tillage, it was 45.7–70.2% in variants with single doses of mineral fertilizers and

Table 4. Effect of organic and mineral fertilizers on sugar beet yield, t/ha

Variant	Plowing		Nonmoldboard		Minimal	
	yield	increase	yield	increase	yield	increase
Grain-grass row						
00	17.7	–	20.5	–	18.8	–
01	26.8	9.1	26.5	6.0	26.0	7.2
02	35.9	18.2	34.6	14.1	33.3	14.5
10	23.0	5.3	24.2	3.7	24.0	5.2
11	31.5	13.8	33.1	12.6	31.2	12.4
12	40.0	22.3	39.1	18.6	38.5	19.7
20	32.6	14.9	31.5	11.0	31.0	12.2
21	40.5	22.8	38.2	17.7	35.7	16.9
22	48.4	30.7	47.1	26.6	45.5	26.7
Grain row crop rotation						
00	16.5	–	16.6	–	18.0	–
01	25.2	8.6	26.8	10.2	23.8	5.8
02	33.5	17.0	32.1	15.5	29.5	11.5
10	23.6	7.1	23.5	6.9	22.9	4.9
11	31.2	14.7	30.1	13.5	28.7	10.6
12	38.8	22.3	36.8	20.2	34.4	16.4
20	32.2	15.6	30.9	14.3	28.0	10.0
21	38.9	22.4	36.4	19.8	33.8	15.8
22	45.7	29.2	41.8	25.2	39.5	21.5
Grain-fallow row crop rotation						
00	13.3	–	17.3	–	16.4	–
01	22.7	9.4	25.8	8.5	23.9	7.5
02	30.8	17.5	32.8	15.5	31.0	14.6
10	20.5	7.2	20.3	3.0	23.1	6.7
11	30.8	17.5	29.9	12.6	30.4	14.0
12	39.8	26.5	38.0	20.7	37.7	21.3
20	27.9	14.6	26.8	9.5	29.7	13.3
21	39.1	25.8	37.5	20.2	37.1	20.7
22	48.9	35.6	46.7	29.4	44.4	28.0

89.5–130.0% in variants with double doses relative to the variant without fertilizers.

Increases in yield were equal to 17.1–42.7% from single doses of manure and 86.8–109.3% from double doses. The maximum yield of sugar beet in the experiment (48.9 t/ha) was in the crop rotation with black fallow and double doses of mineral and organic fertilizers for plowing. The efficiency of both mineral and organic fertilizers was higher against the background of plowing and nonmoldboard tillage, and the efficiency of applying mineral fertilizers at a dose of $N_{180}P_{180}K_{180}$ was significantly higher than at a dose of $N_{90}P_{90}K_{90}$.

CONCLUSIONS

Thus, the grain-grass row crop rotation, the advantage of which was most noticeable on unfertilized backgrounds, where the sugar beet yield exceeded the value of this indicator in the grain-till and grain-fallow crop rotations by 18.4–23.7%, proved to be the most effective. Plowing and nonmoldboard tillage had a noticeable advantage among the studied methods of tillage in relation to the minimum, which increased against backgrounds with double doses of mineral and organic fertilizers.

The introduction of organic fertilizers was most effective in tilled crop rotations when embedding under moldboard plowing, providing a significant increase in sugar beet yield. The use of mineral fertilizers increased the harvest of sugar beet roots by 103.3% relative to absolute control, and the increase reached 173% when they were used together with organic fertilizers. Fertilizer efficiency was higher in row crop rotations with deep embedding.

COMPLIANCE WITH ETHICAL STANDARDS

The study was performed without the use of animals and without involving people as subjects.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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