

Prospects for the ExpressSun™ production system for sunflower cultivation in the European part of Russia

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Abstract. The results of studies of five sunflower cultivation variants within the production system ExpressSun™ on ordinary chernozem for 2013-2019 in the southeastern European part of Russia (the hydrothermal index for the growing season – hereinafter HTI – is 0.70) are presented. It was found that when switching to the systemic principle of formation, cultivation technologies based on differentiated soil tillage in crop rotation provided an increase in soil productive moisture reserve to the emergence of sunflower seedlings, in comparison with the traditional technology by 5.8-12.2 mm (3.8-8.0%), P₂O₅ content - by 2.0-27.2 mg/kg (1.0-8.9%). The highest sunflower oilseed productivity 2.52-2.56 t/ha was revealed when using complex fertilizers, which was 0.25-0.43 t/ha (11.0-20.2%) more than other options. Despite the very high content of K₂O in the soil, the yield was in direct proportion to this macroelement ($r = 0.32-0.85^*$). The highest conditional net income 27070.2 rubles/ha was established against an intensive background of resource-saving technology, which was 970.0-3780.5 rubles/ha (3.7-16.2%) more than other studied options. Based on the data obtained, a low-cost technology of sunflower cultivation has been developed, which includes the following technological operations: applying complex mineral fertilizers (NPK)₁₅, deep soil tillage by 25-27 cm, spring harrowing, pre-sowing cultivation, packing, sowing, harrowing in one track, herbicide treatment, and top-dressing. The expected annual economic effect from the development of new technologies for sunflower cultivation is more than 1100 rubles/ha.

1 Introduction

In the current natural and economic conditions, the most effective and demanded field crop in the European part of Russia is sunflower [1,3,4, 6]. A large number of high-productive and high-quality domestic and foreign hybrids are being cultivated in the region. Adaptive traditional technologies of sunflower cultivation have been developed. However, these technologies do not fully meet the market requirements. Standards for the delivered products have increased, in addition, the situation is complicated by the lack of labor

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resources. In these conditions, it is necessary to search for new approaches and ways, which allow to obtain highly efficient and high-quality yields of sunflower oilseeds while reducing labor costs and applying adaptive intensification [5-6]. The application of new production systems will help solve these problems, but these systems require adaptation to the soil and climatic conditions of the region.

At present, one of the most promising ways for growing sunflower is the production system ExpressSun™ [4]. Its main advantages over other systems are as follows:

- high efficiency against a wide range of dicotyledonous weeds, including malicious and difficult to eradicate (sow thistle species, pigweed, ragweed, etc.);
- post-emergence application of the herbicide: independence from humus content and soil moisture and the ability to see the result of treatment immediately after application;
- safety for the protected and any subsequent culture;
- minimization of stress on sunflower compared to other production systems based on herbicide resistance;
- maximum realization of the productivity potential of hybrids;
- wide range of possible herbicidal treatments from 2 to 8 leaves of the crop;
- synergy of two advanced products: high-yielding sunflower hybrids of the Pioneer company are treated with the high-tech herbicide Express from DuPont to obtain high yields.

In the Volga region, the sown area under this system is currently reaching 15%. However, this technology is not entirely adapted to local conditions.

One of the factors in the implementation of this problem is the use of fertilizers, biological products and microbiological fertilizers, which make it possible to increase soil biological activity, the intensity of photosynthesis and crop productivity [2,8, 9].

Thus, the purpose of the research was to identify the methods of adaptive intensification in sunflower cultivation within the ExpressSun™ production system and the factors that affect the crop yield.

2 Methods

The study of the production system was carried out in grain-and-row crop rotation (black fallow - winter soft wheat - soybeans - spring durum wheat - barley - sunflower) on the experimental fields of the Department of Agriculture and New Technologies of Samara Scientific Research Institute of Agriculture (Bezenchuk, Russia). From 2013 to 2019, five agricultural technologies (experience options) were studied:

1. With annual plowing in a crop rotation by 22-24 cm (control)
2. Control + application of complex mineral fertilizers for basic tillage (NPK)₁₅
3. With differentiated tillage in crop rotation, including for sunflower, deep soil tillage by 25-27 cm (Background)
4. Background + Borogum 1 l/ha (stage 6-8 leaves)
5. Background + application of complex mineral fertilizers for basic tillage (NPK)₁₅.

Borogum B 11 + ME is a liquid boric fertilizer with anti-stress, immunostimulating properties, with a set of microelements in a chelated form. The content of elements in the preparation:

- microelement complex (B 11.0%, Mo 0.005%, Co 0.01%, Cu 0.01%, Zn 0.01%, Mn 0.05%, Ni 0.01%, Li 0.0005%, S 0.01%, Se 0.0001%, Cr 0.001%);
- bioactivated by molecular weight humates 3%, Fitosporin-M 1%.

In the spring-summer period, the following technological operations were applied in all variants of the experiment: early spring harrowing (BZSS-1.0), presowing cultivation by 8-10 cm (OPO-4.25), packing (3KKSh-6), sowing of the hybrid P63LE10 (SSTV-6), harrowing on seedlings (BZSS-1.0), treatment with Express herbicide 50 g/ha (OH-400).

The soil of the study area was ordinary chernozem. The experiment was repeated 3 times, the size of the plots was 1100 m², the placement of the plots was systematic.

Except for 2013 (the hydrothermal index for sunflower vegetation was 0.95), the studies were carried out in arid conditions. In 2014, a spring drought (HTI = 0.58) was identified, in 2015, 2016 and 2018, 2019, a spring-summer drought (HTI = 0.44-0.63). In 2017, with heavy rainfall in May and June, and dry conditions in August, the sunflower oilseed yield was obtained at normal level.

In the experiments, the following records and observations were carried out: soil moisture was determined by the thermostat-weight method, nitrates and mobile forms of phosphorus and potassium - according to GOST 26951-86; 26204-91, the mobile forms of phosphorus and potassium - according to Chirikov.

The results of counts and observations were processed by the analysis-of-variance method (AGROS software version 2.09).

3 Results

On average, over the years of research, the use of deep soil tillage, in comparison with the options where annual plowing was carried out, provided an increase in the reserves of productive moisture in the soil before the emergence of sunflower seedlings by 5.8-12.2 mm (3.8-8.0%) (Table 1).

Table 1. Spring reserves of productive moisture in a meter layer of soil, mm.

Years	Experimental variants					P ≤ 0,05
	1	2	3	4	5	
2013	134.3	112.9	131.8	145.0	135.8	21.0
2014	138.4	141.6	162.1	143.5	154.4	17.2
2015	128.0	124.1	160.7	155.4	147.6	27.7
2016	172.1	183.5	185.5	177.9	177.0	17.0
2017	192.7	201.4	207.6	194.5	199.0	12.8
2018	150.6	155.3	150.1	148.4	149.1	20.6
2019	152.9	156.9	156.7	151.6	155.8	11.5
Average	152.7	153.7	164.9	159.5	159.8	18.3

However, at the same time, a reliable advantage of a plowless tillage (natural background in terms of fertility) was established only in 2014, 2015, and 2017.

When monitoring the reserves of productive moisture, it was found that, by the time of harvest, the indicator was equalized depending on the options studied (Figure 1).

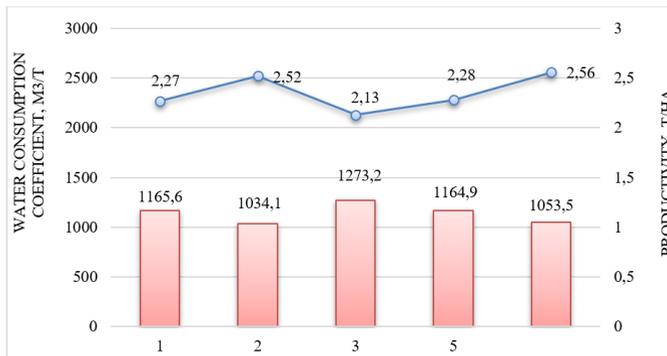


Fig. 1. Water consumption coefficient and productivity of sunflower.

The highest water consumption coefficient was established for the option with resource-saving technology without the use of fertilizers - 1273.2 m³/ha.

In our studies, during the period of sunflower seedlings, the use of annual plowing in the studied crop rotation provided a significant improvement in the nitrogen regime of the soil by 7.9-17.2 mg/kg (36.5-65.6%) compared with the variants where plowless tillage was carried out (2013, 2018, and 2019) (Table 2).

Table 2. The content of mobile nutrients under sunflower crops in spring in the soil layer 0-40 cm, mg/kg (average 2013-2019).

Soil nutrients	Experimental variants					P ≤ 0,05
	1	2	3	4	5	
NO ₃	33.1	40.2	27.8	27.3	34.0	8.1
P ₂ O ₅	182.7	197.9	199.9	205.8	209.9	22.1
K ₂ O	177.9	187.4	184.8	179.7	190.8	21.2

In other years and on average for the period under study, the difference between the variants in terms of NO₃ content was insignificant and amounted to 5.3 mg/kg soil

With the exception of 2014 and 2015, the sunflower productivity 2.13-2.56 t/ha was at the level and above the average long-term values. The use of plowing on a natural fertile background (variant 1) increased the yield of sunflower compared to soil deep tillage without the use of fertilizers in 2017-2019, however, on average, over the years of research, the difference between the options was not significant (Table 3).

Table 3. Sunflower productivity, reduced to 8% grain moisture, t/ha.

Years	Experimental variants					P ≤ 0,05
	1	2	3	4	5	
2013	2.41	2.82	2.28	2.57	2.90	0.33
2014	1.82	2.04	1.60	1.79	2.25	0.22
2015	1.09	1.30	1.29	1.43	1.52	0.18
2016	2.94	3.07	2.83	2.96	3.07	0.14
2017	2.30	2.37	2.15	2.18	2.40	0.14
2018	2.40	2.58	2.08	2.21	2.41	0.22
2019	2.93	3.45	2.67	2.80	3.39	0.17
Average	2.27	2.52	2.13	2.28	2.56	0.20

Reducing production costs with the use of soil deep tillage (3rd, 4th options) by 5.2-9.3% in comparison with the control contributed to an increase in the production profitability by 9.5-21.2% (Table 4).

Table 4. Economic efficiency of sunflower cultivation (average for 2013-2019).

Experim ental variants	Production costs, rubles/ha	Operating costs, rubles/ha	Conditional net income, rubles/ha	Profitability, %
1	34495.6	10003.0	24492.6	244.9
2	38180.7	12080.5	26100.2	216.1
3	32444.4	9154.7	23289.7	254.4
4	34810.0	9508.5	25301.5	266.1
5	38222.4	11152.2	27070.2	242.7

The highest conditional net income was established within intensive backgrounds of resource-saving and traditional technology - 26,100.2-27070.2 rubles/ha, which was 798.7-

1768.7 rubles/ha (3.2-7.0%) more than the option with deep tillage and processing crops with a biological product. The lowest economic indicators were obtained on extensive backgrounds of resource-saving and traditional technologies.

4 Discussion

When analyzing the dependence of the productive moisture reserves on abiotic factors in the 0-100 cm soil layer during the sunflower seedling period, in the option with plowing, a significant at 1% level correlation was established ($r = 0.93-0.94^{**}$) with the amount of precipitation for the non-growing period (September-April), preceding the sowing of sunflower. Due to the better moisture accumulation, the use of deep soil tillage within the natural background in terms of fertility (3rd, 4th variants) reduced the dependence of the reserves of productive moisture on the moisture conditions in the autumn-winter period to 5% of the significance level ($r = 0.79^*-0.80^*$). Within the intensive background of resource-saving technology, the relationship between the indicators was of an intermediate level ($r = 0.87^{**}$). Productive moisture reserves were in an average inverse relationship with the HTI in May, with a correlation coefficient from -0.71 to -0.81*.

However, in the arid conditions of the region, the application of complex fertilizers, both with traditional technology and resource-saving, contributed to a more rational consumption of moisture per unit of production, compared with plowless soil tillage using a biological product and traditional technology by 10.6-12.7%, up to 1034.1-1053.5 m³/ha.

With a high and very high content of mobile phosphates and exchangeable potassium on most chernozems, nitrogen is one of the main macroelements affecting the yield of agricultural crops in the Middle Volga region and in the south of the European part of Russia [7, 9, 10].

The introduction of complex fertilizers, both on plowing and during deep soil tillage, in most years increased the content of nitrates, however, on average, over the years of research, the difference between fertilized and unfertilized options was 6.7-7.1 mg/kg (21.5-24.5) and it was not mathematically provable.

The accumulation of nitrates to sunflower seedlings, in the variant with plowing without the use of fertilizers, was positively influenced by the average air temperature in May ($r = 0.83^*$).

With deep soil tillage, due to its less warming up and, accordingly, a decrease in the microbiological activity of the soil, the relationship with the average daily temperature in May was less significant ($r = 0.64$). On the variants with the use of fertilizers, the amount of NO₃ was sufficient for the normal growth and development of plants, and therefore the relationship between the indicator and the air temperature was not significant. The increase in precipitation during the off-growing period contributed to the washing of nitrates into the soil layer below 0-40 cm. As a result, the relationship between the content of NO₃ and the amount of precipitation was inverse, with $r =$ from -0.33 to -0.58.

In the conducted studies, an improvement in the phosphorus regime of the soil was established when using deep soil tillage for sunflower, in comparison with plowing by 17.2-23.1 mg/kg (10.2-14.4%). The introduction of complex fertilizers ensured the leveling of indicators between different methods of basic soil cultivation. The change in the potassium regime of the soil, depending on the studied variants, was not significant.

The accumulation of mobile phosphates and exchangeable potassium from abiotic factors in the option with plowing was positively influenced by the air temperature during the non-growing period preceding the sowing of sunflower ($r = 0.70-0.73$). With deep soil tillage, the P₂O₅ content, depending on the air temperature for the same period, was at the level with the control ($r = 0.61-0.75$), the K₂O content depended more on the amount of precipitation (September-April), with a correlation coefficient equal to 0.68-0.81*. There

was a direct relationship between the content of exchangeable potassium and mobile phosphorus ($r = 0.75-0.81^*$).

When cultivating sunflower, it is important to ensure low contamination of crops in the initial phases of its development. Harrowing of crops by seedlings during the years of research contributed to a decrease in weediness to a low and medium level. Subsequently, the postemergence herbicide Express, applied to sunflowers, showed high biological effectiveness. After treatment with herbicide, the weediness of crops during the entire growing season was at a low level, the remaining weeds were suppressed and did not significantly affect the yield of oilseeds of the studied crop.

When observing after chemical treatment, the phytotoxic effect of the applied herbicide Express on the hybrid P63LE10 was not established.

The application of fertilizer Borogum, on average over the years of research, ensured that the yield of sunflower was at the level with the control and by 0.15 t/ha (6.0%) more than in the variant without the use of a biological product.

The highest yield of sunflower oil seeds 2.52-2.56 t/ha was established with the use of complex mineral fertilizers. The increase from this agricultural method using traditional technology was 0.25 t/ha (11.0%). With resource-saving technology, the responsiveness to improving the mineral nutrition of plants increased by 0.43 t/ha (20.2%).

According to the results of the correlation analysis, it was found that in the variant with plowing, the oilseed yield was significantly dependent on the soil K_2O content during the period of crop emergence ($r = 0.71-0.85^*$). With deep soil tillage, the sunflower productivity was also influenced to a greater extent by the content of exchangeable potassium ($r = 0.32-0.50$), while the smallest relationship was found in the variant with the use of a biological product.

When analyzing climatic conditions, it was revealed that the sunflower yield with annual plowing was the most dependent on the temperature and relative humidity of the air in September ($r = 0.76^* -0.81^*$). The connection was inverse in the first case, in the second, it was direct.

With deep soil tillage without the use of mineral fertilizers, the maximum relationship was established with the relative humidity and air temperature in September ($r = 0.80^*-0.86^*$ and $-0.74 - -0.76^*$, respectively), which had a positive effect on filling oilseeds. The dependence on precipitation and the HTI in September was less significant ($r = 0.62-0.71$). With the improvement of the mineral nutrition of plants, the yield of oilseeds depended to the greatest extent on air temperature ($r = -0.88^{**}$) and relative humidity ($r = 0.80^*$) in September. The amount of precipitation and the HTI during this period did not have a significant effect on the yield ($r = 0.48-0.53$).

5 Conclusions

Study of the intensification elements in sunflower cultivation in the production system ExpressSun™ carried out for the period 2013-2019 revealed the great prospects of this direction.

The possibility of effective use of cultivation technologies based on differentiated tillage in crop rotation providing an increase in the reserves of soil productive moisture to the emergence of sunflower seedlings in comparison with the traditional technology by 5.8-12.2 mm (3.8-8.0%) as well as P_2O_5 content by 2.0-27.2 mg/kg (1.0-8.9%) was shown.

The highest yield of sunflower oilseeds .52-2.56 t/ha was established with the use of complex fertilizers. The increase from this agricultural method using traditional technology was 0.25 t/ha (11.0%), with resource-saving technology, it was 0.43 t/ha (20.2%). The indicator significantly depended on the content of exchangeable potassium in the soil

during the period of crop emergence. Among abiotic factors, the yield was influenced by the temperature and relative air humidity during the period of oilseed filling in September.

The highest conditional net income 26100.2-27070.2 rubles/ha was established within intensive backgrounds of resource-saving and traditional technology. The maximum profitability with deep soil tillage using a biological product was 266.1%.

Based on the data obtained, a low-cost technology for sunflower cultivation has been developed, which includes the following technological operations: the introduction of complex mineral fertilizers (NPK)₁₅, deep soil tillage by 25-27 cm, spring harrowing, pre-sowing cultivation, packing, sowing, harrowing in one track, herbicide treatment (Express, 50 g/ha), and top-dressing in the phase of 8-10 true leaves (Borogum, 1 l/ha). In the region, the expected annual economic effect from the development of new technologies for sunflower cultivation is more than 1100 rubles/ha.

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