The effect of tillage in combination with the use of fertilizers and protective equipment on the yield and economic efficiency of crop cultivation in the North-Eastern region of the central chernozem zone

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Abstract. The studies were carried out on typical chernozem. The purpose of the research was to develop resource-saving technological methods of crop cultivation, ensuring an increase in yield and economic efficiency of production. The work was carried out in a long-term stationary field experiment against the background of two types of crop rotations: in 2007-2010 – grain-fallow-hoe (black fallow – winter wheat – sugar beet – barley) and in 2013-2020 – grain-fallow (black fallow – winter wheat – soy – barley). Four systems of basic tillage were compared in the grain-fallow-hoe crop rotation: traditional dump multi-depth, surface, non-dump multi-depth, combined (25% dump + 75% non-dump). There are five tillage systems in the grain-fallow crop rotation, with the inclusion of a combined system in the experiment scheme (25% dump + 75% surface). Fertilizers and plant protection products were used against the background of treatments for crop rotation cultures. The best conditions for the formation of crop yields, arable land productivity in crop rotations and the best economic indicators are formed with combined (25% dump and 75% non-dump) and (25% dump + 75% surface) tillage systems in combination with a low level of mineral nutrition and plant protection products. An increase in the level of mineral nutrition in crop rotations without the use of plant protection products leads to a significant decrease in the economic efficiency of production.

1 Introduction

The traditional system of chernozem soil processing in the conditions of the north-east of the CCR is considered to be multi-depth dump plowing, which to a certain extent restrains the spread of harmful objects in agrocenoses. At the same time, the use of such processing in crop rotations leads to an increase in production costs and a decrease in the economic efficiency of production [1]. In modern conditions, in crop production, there is a radical

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reassessment of the applied technological complexes of crop cultivation in the direction of energy conservation, which is becoming an increasingly urgent problem every year [2-5].

In agriculture, energy saving is based on the search for ways to reduce the cost of tillage as the most time-consuming process and optimize the use of chemicals as the most expensive in technological complexes of crop cultivation. At the same time, both high intensity and excessive minimization of tillage leads to deterioration of soil properties, reduces the level of mineral nutrition and soil fertility, and as a result, crop yields [6-8].

The use of minimal and especially zero soil treatments in technological complexes of crop cultivation is accompanied not only by a decrease in energy consumption, but also by a significant decrease in the arable land productivity [9-11]. At the same time, there are studies indicating the positive impact of crop cultivation technology without tillage, which provides an increase in yield and an increase in the economic efficiency of production [12].

In connection with the transition to energy-saving technologies, there is a need to determine the feasibility of using minimization of tillage in combination with chemicalization means, as well as to assess their impact on soil fertility and crop yields in specific soil and climatic conditions.

Considering this, the purpose of our research was to study the effect of technologies for cultivating crops of grain-fallow-hoe and grain-fallow crop rotations, typical for the region, on crop yields, arable land productivity and the economic efficiency of crop production in the zone of unstable humidification of the northeastern part of the Chernozem region.

2 Materials and Methods

To achieve this goal, studies were conducted in the experimental field of the Tambov Research Institute of Agriculture in a stationary multifactorial field experiment against the background of grain-fallow-hoe crop rotation: black fallow – winter wheat – sugar beet – barley, and grain-fallow crop rotation (black fallow – winter wheat - soy - barley) typical for the region.

The soil of the experimental site is typical heavy loamy chernozem, with favorable physico-chemical indicators. The humus content in the soil layer of 0-30 cm is 6,7-7,3%, the availability of the main available forms of mineral nutrition (nitrogen, phosphorus, and potassium) is high.

The experiment is based on three-fold repetition. The placement of plots and repetitions is systematic. The scheme of the experiment is based on the method of split plots. Plots of the first order (tillage) – 52 x 7 m, area - 364 m^2. Plots of the second order (fertilizer) – 17 x 7 m, area - 119 m^2. Plots of the third order (pesticides) – 8.5 x 7 m, area - 59.5 m^2. The registered area of the plot is 25 m^2 (5 x 5 m).

Various tillage systems were studied in the experiment. The scheme of stationary experiment included the following options: traditional dump multi-depth (control); permanent surface (disking to 10-12 cm); permanent non-dump multi-depth; combined (25% dump + 75% non-dump); in the grain-fallow crop rotation, a combined option (25% dump + 75% surface) processing system is additionally included.

Within the framework of the dump system (control), the main tillage was carried out by plowing with a plow PLN-5-35 for sugar beet 27-30 cm, soy – 25-27 cm, cereals (winter wheat, barley) – 20-22 cm.

The surface system provided for the main treatment with a BDM 3 x 4P discator for 10-12 cm for all crops of crop rotations.

The main processing with non-dump system was carried out with a plow PLN-5-35 without dumps for sugar beet to 27-30 cm, soy – to 25-27 cm, for grain crops of crop rotations – to 20-22 cm.

When using a combined non-dump system of the main processing, plowing was carried out for sugar beet and soy, and non-dump processing for grain crops of crop rotations, where plowing occupied 25%, non-dump processing - 75%.

The combined dump-surface system provided for plowing for soy, surface treatment - for cereals, where plowing occupied 25%, and surface treatment - 75%.

The depth of tillage with combined systems was the same as in previous versions of the experiment.

Basic tillage was studied at three levels of mineral nutrition in crop rotations – high, medium, and low. In the grain-fallow-hoe crop rotation, the fertilizer application rate at a high level was in $N_{80}P_{80}K_{80}$ kg r.a. per 1 ha of arable land, including $N_{120}P_{120}K_{120}$, winter wheat and barley at $N_{60}P_{60}K_{60}$, at an average level - $N_{53}P_{53}K_{53}$, where $N_{90}P_{90}K_{90}$ was introduced for sugar beet, $N_{30}P_{30}K_{30}$ - for winter wheat, for barley – $N_{40}P_{40}K_{40}$; at low levels – $N_{40}P_{30}K_{30}$, including $N_{60}P_{60}K_{60}$ for sugar beet, winter wheat - N_{30} in spring feeding, barley – $N_{30}P_{30}K_{30}$.

In the grain-fallow crop rotation, the high level of mineral nutrition was in $N_{60}P_{60}K_{60}$ kg r.a. per 1 ha of arable land, including $N_{60}P_{60}K_{60}$ for all crops; the average level – $N_{33}P_{33}K_{33}$, where for winter wheat – $N_{30}P_{30}K_{30}$, for soy – $N_{30}P_{30}K_{30}$ and for barley – $N_{40}P_{40}K_{40}$; low level – $N_{20}P_{10}K_{10}$, including winter wheat – N_{30} for top dressing, barley – $N_{30}P_{30}K_{30}$, for soy – without fertilizers.

The plant protection system consisted of two levels: seed dressing – background; background + herbicides, fungicides, and insecticides for the vegetation of crop rotation cultures.

Observations and records were carried out according to the current methods adopted in field research on agriculture [13]. The economic efficiency of technologies, doses of applied fertilizers, and plant protection products was determined by the method [14].

Agrometeorological conditions in the years of research during the growing season (May – August) were quite contrasting. The years 2008, 2013, 2015-2017 were very favorable in terms of moisture availability for crops, when, on average, during the growing season, the amount of precipitation varied between 186-424 mm, with an average annual value of 204 mm. The temperature regime in these years was 18.2-20.8°C, which is 0.4-3.0°C higher than average long-term readings (17.8°C).

Growing periods of 2007, 2009, 2010, 2018, 2019, 2020 years were characterized by a lack of precipitation, 46.8-155,2 mm lower than the average long-term values and increased temperature regime by 0.4-5.2°C. At the same time, the vegetation periods were acutely arid in 2009, 2010, the amount of precipitation was 47.0 and 54% of the norm, and the temperature regime was 4.3-5.2°C above the long-term average. The vegetation periods in 2018-2020 were also acutely arid, precipitation fell by 68.0-155.2 mm less, and the temperature regime was 1.2-1.6°C higher than the norm.

The prevailing weather conditions during the years of research contributed to an objective assessment of the studied factors and the reliability of the revealed patterns of formation of yield and productivity of arable land in crop rotations, depending on the studied techniques of technologies.

3 Results and Discussion

Crop yield is the resulting indicator of all conditions and the main criterion for assessing the effectiveness of agrotechnical techniques.

Analyzing the yield value (Tables 1, 2), it can be noted that it depended to a certain extent on agrotechnical techniques in crop cultivation technologies in crop rotations. Thus, in the variants with permanent surface and non-dump tillage systems, the yield of winter wheat decreased, compared with the control, by 0.35 and 0.15 t/ha without protective equipment complex and by 0.21 and 0.22 t/ha with the use of plant protection products. In variants with a combined non-dump processing system, the difference in yield, compared with the control, was within the experiment error (Table 1).

The maximum yield of sugar beet root crops in the experiment was achieved using a combined non-dump tillage system in the crop rotation, where plowing was carried out for sugar beet. Against the background without plant protection products, the yield was 58.4 t/ha, with the use of protection products – 62.2 t/ha, which is 1.9 and 1.6 t/ha more than the control (traditional dump multi-depth processing system). Replacement of plowing by surface treatment led to a decrease in yield by 5.0 t/ha without protective equipment and by 4.1 t/ha with the use of protection products.

In the technologies of barley cultivation, the most acceptable were the traditional dump and combined dump-surface ones, where plowing and surface treatment were carried out for barley. The yield on these variants was formed at the level of 3.40-3.46 t/ha without protective equipment and 3.79-3.73 t/ha with the use of a complex of plant protection products. In the technology with surface treatment, the yield, compared with the control, decreased by 0.48 t/ha without protection products and by 0.64 t/ha with plant protection products. In the variants with a permanent non-dump treatment system, a decrease in yield was also noted, but to a lesser extent than against the background of surface treatment – 0.19 and 0.29 t/ha, compared with the control.

In terms of the yield of grain units from 1 ha of arable land in crop rotation, the combined dump-free tillage system has an advantage over the traditional dump system – 5,78-6,18 t/ha (by 0.45 and 1.53 t/ha). There was a decrease in the yield of grain units and in the permanent non-dump treatment system - by 0.19 and 0.09 t /ha, compared with the control.

Crop rotation cultures reacted differently to the increase in fertilizer application doses. If winter wheat responded poorly to an increase in the dose of fertilizers, the difference in yield by dose was at the determination accuracy level, then sugar beet and barley significantly increased productivity from an increase in doses of fertilizers. The maximum yield of sugar beet root crops was obtained on variants with the introduction of $N_{120}P_{120}K_{120}$ – 56.7 t/ha without plant protection products and 61.6 t/ha with protection products, or an increase compared to the dose of $N_{60}P_{60}K_{60}$ was 3.00-3.20 t/ha.

Increasing the dose of fertilizers for barley from $N_{30}P_{30}K_{30}$ to $N_{60}P_{60}K_{60}$ significantly increased the yield of this crop. The increase was 0.28 t/ha without protective equipment and 0.36 t/ha in combination with plant protection products (with LSD_{05} for fertilizers = 0.11-0.16 t/ha).

The most significant increases in crop yields were provided by options with the use of complex plant protection measures in cultivation technologies (seed dressing + pesticides for crop vegetation), for winter wheat – 0.32 t/ha, sugar beet – 4.74 t/ha, and barley – 0.27 t/ha on average according to the experimental options.

According to the yield of grain units, the variants with a high level of mineral nutrition $N_{80}P_{80}K_{80}$ in combination with plant protection products had an advantage, which averaged 6.11 t/ha according to the experimental variants. The increase compared to the low level of mineral nutrition $N_{40}P_{30}K_{30}$ was 0.48 t/ha of grain units.

In the grain-fallow crop rotation, technological cultivation complexes based on traditional dump and combined dump-surface systems of basic tillage – 2.31 and 2.99 t/ha without protection products and 2.67 and 2.68 t/ha using a complex of protection products had some advantage in the yield of grain units. The use of a permanent surface tillage system in crop rotation reduced the yield of grain units, compared with the control (traditional dump system) by 0.15 and 0.11 t/ha, respectively, without protection products and with the use of such. There was a slight decrease in this indicator in the variants with permanent non-dump and combined non-dump tillage systems, amounting to 0.07-0.02 t/ha without protection products, and 0.08-0.10 t/ha in combination with protection products (Table 2).

Of the crop rotation cultures, barley is the most responsive not only to tillage, but also to increasing the level of mineral nutrition. Replacement of plowing, during the main tillage, by surface treatment, significantly reduced the yield of barley (by 0.59 t/ha) in the variant without the use of protection products and by 0.27 t/ha against the background of plant protection from harmful objects. At the same time, the use of surface treatment in combination with plant protection products for barley in a combined dump-surface system in crop rotation ensured the formation of yields at the control level.

An increase in the dose of fertilizers from $N_{30}P_{30}K_{30}$ to $N_{60}P_{60}K_{60}$ contributed to an increase in the yield of barley, on average according to the experimental variants by 0.46 t/ha without protection products and by 0.68 t/ha in combination with plant protection products.

Soy and winter wheat react differently to fertilization. On average, according to the experimental variants, the yield of soy on a fertilized background $N_{60}P_{60}K_{60}$ was 1.52 t/ha, without fertilizers – 1.43 t/ha, the difference of 0.09 t/ha was insignificant and was within the determination accuracy. The same can be said about winter wheat crops, the yield of which was the same at different levels of mineral nutrition – 4.83 t/ha when adding N_{30} to the top dressing and 4.84 t/ha on the variant with $N_{30}P_{30}K_{30}$ and 4.90 t/ha against the background of $N_{60}P_{60}K_{60}$.

Table 1. Yield of field crops and productivity of arable land depending on technological methods of cultivation in the grain-fallow-hoe crop rotation, t/ha (on average for 2007-2010).

System of basic tillage in crop rotation	Level of mineral nutrition kg/ha r.a.	Plant protection system	Winter wheat	Sugar beet	Barley	Product yield from 1 ha of arable land, tons grain units
Traditional dump multi-depth (control)	$N_{40}P_{30}K_{30}$	1^{x}	4.29	54.2	3.27	5,41
		2^{xx}	4.69	59.2	3.57	5,91
	$N_{53}P_{53}K_{53}$	1	4.63	56.8	3.44	5,71
		2	4.89	59.7	3.79	6,05
	$N_{80}P_{80}K_{80}$	1	4.61	58.4	3.48	5,82
		2	4.74	62.8	3.79	6,21
Average by soil tillage variant		1	4,51	56.5	3.40	5.65
		2	4,77	60.6	3.72	6.06
Permanent surface (disking to 10-12 cm)	$N_{40}P_{30}K_{30}$	1	4.06	49.3	2.81	4,92
		2	4.37	54.1	2.92	5,34
	$N_{53}P_{53}K_{53}$	1	4.25	52.1	2.92	5,18
		2	4.55	57.1	3.22	5,65
	$N_{80}P_{80}K_{80}$	1	4.18	53.1	3.04	5,25
		2	4.77	58.6	3.32	5,83
Average by soil tillage variant		1	4,16	51.5	2.92	5.12
		2	4,56	56.6	3.15	5.61
Permanent non-dump multi-deep	$N_{40}P_{30}K_{30}$	1	4.30	53.3	3.00	5,29
		2	4.51	60.5	3.30	5,88
	$N_{53}P_{53}K_{53}$	1	4.41	55.6	3.26	5,53
		2	4.54	60.8	3.49	5,96
	$N_{80}P_{80}K_{80}$	1	4.36	56.0	3.38	5,57
		2	4.60	61.5	3.72	6,08
Average by soil tillage		1	4,36	55.0	3.21	5.46

variant		2	4,55	60.9	3.50	5.97
Combined (dump-non-dump)	$N_{40}P_{30}K_{30}$	1	4.29	57.1	3.28	5,60
		2	4.90	60.8	3.59	6,07
	$N_{53}P_{53}K_{53}$	1	4.57	58.6	3.54	5,84
		2	4.74	62.1	3.64	6,13
	$N_{80}P_{80}K_{80}$	1	4.53	59.4	3.57	5,89
		2	4.78	63.7	3.97	6,33
Average by soil tillage variant		1	4,46	58.4	3.46	5.78
		2	4,81	62.2	3.73	6.18
LSD_{05} for average quotient			0.25-0.50	3.35-7.86	0.23-0.50	
soil tillage			0.11-0.30	1.43-3.40	0.11-0.30	
fertilizers			0.08-0.27	1.08-2.84	0.11-0.16	
plant protection products			0.07-0.13	1.00-2.30	0.10-0.13	

Note: 1^x – seed dressing (background); 2^{xx} – background + pesticides for growing crops

Plant protection products had a significant impact on crop yield and yield of grain units in the grain-fallow, as well as in the grain-fallow-hoe crop crop rotation. Technological complexes of crop cultivation with the use of plant protection products (seed dressing + pesticides for crop vegetation) provided the yield of grain units from 1 ha of arable land, on average, according to the variants – 2.61 t/ha, which is 0.35 t/ha higher than the variants using only seed dressing.

The expediency of using this or that technique in technological complexes of crop cultivation depends on their economic efficiency.

The calculation of the economic efficiency of crop production in crop rotations with various technological complexes of crop cultivation has shown that the best efficiency indicators in grain-fallow-hoe crop rotation are provided by the use of technologies based on a combined dump-non-dump system of basic tillage, in grain-fallow – with permanent surface and combined dump-surface tillage systems in a complex with a low level of mineral nutrition - $N_{40}P_{30}K_{30}$ and $N_{20}P_{10}K_{10}$ and the second level of plant protection (Table 3). The cost recovery in these variants was 3.28, 3.50, and 3.54 rub./rub, with the indicator on the control 3.15 and 3.40 rub./rub.

Table 2. Yield of field crops and productivity of arable land depending on technological methods of cultivation in the grain-fallow crop rotation, t/ha (on average for 2013-2020)

System of basic tillage in crop rotation	Level of mineral nutrition kg/ha r.a.	Plant protection system	Winter wheat	Soy	Barley	Product yield from 1 ha of arable land, tons grain units
Traditional dump multi-depth (control)	$N_{60}P_{60}K_{60}$	1^x	4.66	1.35	3.28	2,38
		2^{xx}	5.21	1.71	3.94	2,79
	$N_{33}P_{33}K_{33}$	1	4.65	1.36	3.18	2,35
		2	5.18	1.61	3.58	2,66
	$N_{20}P_{10}K_{10}$	1	4.24	1.37	2.92	2,19
		2	5.18	1.61	3.24	2,58
Average by soil tillage variant		1	4,52	1.36	3.13	2.31
		2	5,19	1.64	3.59	2.67

Permanent surface (disking to 10-12 cm)	$N_{60}P_{60}K_{60}$	1	4.61	1.26	3.20	2,32
		2	5.12	1.69	3.70	2,70
	$N_{33}P_{33}K_{33}$	1	4.60	1.25	2.83	2,22
		2	5.09	1.51	3.25	2,53
	$N_{20}P_{10}K_{10}$	1	4.77	1.23	2.59	2,20
		2	5.03	1.51	2.98	2,44
Average by soil tillage variant		1	4,66	1.25	2.54	2.16
		2	5,08	1.57	3.31	2.56
Permanent non-dump multi-deep	$N_{60}P_{60}K_{60}$	1	4.67	1.23	3.07	2.29
		2	5.12	1.70	3.76	2.72
	$N_{33}P_{33}K_{33}$	1	4.57	1.25	2.89	2.23
		2	4.92	1.56	3.52	2.57
	$N_{20}P_{10}K_{10}$	1	4.58	1.28	2.72	2.20
		2	4.94	1.53	3.17	2.47
Average by soil tillage variant		1	4,60	1.25	2.89	2.24
		2	4,99	1.60	3.48	2.59
Combined (dump-non-dump)	$N_{60}P_{60}K_{60}$	1	4.69	1.31	3.26	2.37
		2	5.19	1.71	3.95	2.78
	$N_{33}P_{33}K_{33}$	1	4.57	1.33	2.97	2.27
		2	4.98	1.58	3.50	2.58
	$N_{20}P_{10}K_{10}$	1	4.68	1.27	2.75	2.23
		2	5.05	1.53	3.20	2.51
Average by soil tillage variant		1	4,65	1.30	2.99	2.29
		2	5,07	1.61	3.55	2.57
Combined dump-surface	$N_{60}P_{60}K_{60}$	1	4.64	1.40	3.30	2.39
		2	5.14	1.82	3.90	2.79
	$N_{33}P_{33}K_{33}$	1	4.68	1.41	2.83	2.29
		2	5.16	1.64	3.63	2.68
	$N_{20}P_{10}K_{10}$	1	4.74	1.33	2.85	2.29
		2	5.08	1.65	3.28	2.57
Average by soil tillage variant		1	4.69	1.38	2.99	2.32
		2	5.13	1.70	3.60	2.68
LSD_{05} for average quotient			0.10-0.67	0.10-0.30	0.14-0.53	
soil tillage			0.30-0.35	0.03-0.12	0.04-0.22	
fertilizers			0.03-0.40	0.04-0.20	0.05-0.17	
plant protection products			0.04-0.51	0.03-0.08	0.06-0.19	

Note: 1^x – seed dressing (background); 2^{xx} – background + pesticides for growing crops.

An increase in the level of mineral nutrition to $N_{80}P_{80}K_{80}$ in the grain crop rotation led to a decrease in cost recovery, in the best case up to 2.69 rub./rub. or 0.59 rub. compared to the low background of mineral nutrition $N_{40}P_{30}K_{30}$. In the grain-fallow crop rotation, the use of a high level of mineral nutrition $N_{60}P_{60}K_{60}$ kg r.a. per 1 ha of arable land also worsened economic indicators, cost recovery decreased to 2.45 and 2.57 rub./rub. in the best variants or by 1.05 and 0.97 rub./rub., compared with a low level of mineral nutrition $N_{20}P_{10}K_{10}$.

The economic indicators were also worsened by the use of the first level of plant protection (seed dressing) in crop cultivation technologies in crop rotations.

The establishment of regularities in the effect of technological techniques on the economic efficiency of production was also characteristic of other technological complexes of crop cultivation in crop rotations.

In the grain-fallow-hoe crop rotation, from the standpoint of economic assessment, the use of a permanent surface tillage system (disking to 10-12 cm) is less costly, but also less profitable in crop cultivation technologies, compared with the traditional dump multi-depth tillage system.

Table 3. Economic indicators of production depending on the technological methods of crop cultivation in the crop rotation.

Crop rotation	Level of mineral nutrition kg/ha r.a.	Tillage system in crop rotation									
				Permanent				Combined			
		Traditional dump multi-depth (control)		Surface (disking to 10-12 cm)		non-dump multi-depth		dump-non-dump		dump-surface	
		1*	2**	1*	2**	1*	2**	1*	2**	1*	2**
Grain-fallow-hoe, (average for 2007-2010)	$N_{80}P_{80}K_{80}$	16.65 2.55	17.96 2.60	16.27 2.34	16.77 2.46	16.51 2.46	17.12 2.60	16.79 2.57	17.19 2.69	X	X
	$N_{53}P_{53}K_{53}$	14.80 2.82	15.21 2.90	14.16 2.65	14.59 2.82	14.45 2.79	14.99 2.91	14.84 2.89	15.17 2.97	X	X
	$N_{40}P_{30}K_{30}$	13.13 3.01	13.68 3.15	12.59 2.83	13.16 2.94	12.80 3.03	13.53 3.21	13.10 3.13	13.67 3.28	X	X
Grain-fallow (average for 2013-2020)	$N_{60}P_{60}K_{60}$	14.69 2.25	15.63 2.42	14.10 2.24	14.89 2.45	14.22 2.25	15.16 2.38	14.50 2.26	15.32 2.49	14.53 2.33	15.17 2.57
	$N_{33}P_{33}K_{33}$	11.92 2.72	12.81 2.87	11.38 2.68	12.15 2.90	11.55 2.66	12.41 2.85	11.70 2.72	12.48 2.86	11.62 2.89	12.41 3.05
	$N_{20}P_{10}K_{10}$	10.09 3.18	10.67 3.40	9.36 3.34	10.15 3.50	9.02 3.17	10.53 3.29	9.68 3.28	10.44 3.39	9.61 3.40	10.40 3.54

Note: 1* – seed dressing (background); 2^{xx} – background + pesticides for growing crops;
Numerator – costs, thousand rub./ha, denominator – cost recovery, rub./rub.

In the grain-fallow crop rotation, the use of permanent surface and other resource-saving systems of basic tillage in technological complexes of crop cultivation did not differ significantly in economic efficiency from the traditional dump processing system.

4 Conclusions

1. In the soil and climatic conditions of the CCZ in field crop rotations, the use of agrotechnological methods of crop cultivation should be differentiated by the agrobiological requirements of the crops for which they are carried out.

2. On typical chernozem with good physico-chemical properties with high availability of available forms of nutrition elements, energy-saving crop cultivation complexes are promising, which include short-rotation grain-fallow-hoe crop rotations, minimal systems of basic tillage, resource-saving systems of fertilizers, and plant protection products.

3. In the grain-fallow-hoe crop rotation: black fallow – winter wheat – sugar beet – barley, the most effective technological complexes of crop cultivation based on a combined (25% dump + 75% non-dump) system of basic tillage, it is advisable to plow to a depth of 25-30 cm for sugar beet, for winter wheat and barley – tillage to a depth of 20-22 cm, in a complex with a low level of mineral nutrition $N_{40}P_{30}K_{30}$ kg r.a. per 1 ha of arable land, including foe winter wheat – N_{30} in top dressing, barley – $N_{30}P_{30}K_{30}$ and sugar beet – $N_{60}P_{60}K_{60}$ in combination with plant protection products.

4. In crop rotations of this type, surface tillage cannot be a system one, its application is possible for individual cultures of crop rotation.

5. In the grain-fallow crop rotation: black fallow – winter wheat – soy – barley, along with combined systems (25% dump + 75% non-dump) and (25% dump and 75% surface), it is possible to use surface and non-dump multi-depth tillage systems. The essential condition for the effectiveness of technologies based on energy-saving techniques is optimal saturation with fertilizers $N_{20}P_{10}K_{10}$, including for winter wheat – N_{30} for top dressing, barley – $N_{30}P_{30}K_{30}$, and soy should be cultivated without fertilizers in combination with plant protection products.

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