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PRODUCTIVITY, ECONOMIC AND ENERGY EFFICIENCY OF SHORT CROP ROTATION UNDER DIFFERENT SYSTEMS OF BASIC TILLAGE AND FERTILIZATION IN THE RIGHT BANK FOREST STEPPE OF UKRAINE

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Abstract

The efficiency of four systems of basic soil tillage and four systems of crop fertilization of five-field crop rotation was studied. Areas of cultivation options were systematically placed in one tier, and fertilizers – in four tiers in a row. Plowing was carried out with a plow, tillage with a deep cultivator, and shallow plowing with a heavy disc harrow. The highest yields of soybeans, winter wheat and corn were under mouldboard, and sunflower and spring barley – under mouldboardless tillage in crop rotation. Under systematic mouldboardless and disk tillage in crop rotation, the yield of all crops decreased significantly, and with increasing fertilizer rates, the difference between these cultivation options and control increased. Crop rotation productivity was almost at the same level under mouldboard and mouldboardless tillage; under the other studied options it was significantly lower. In terms of economic and energy efficiency, under differentiated cultivation the advantage was with the application of 12 tons of manure per hectare of arable land + $N_{95}P_{82}K_{72}$. In terms of crop rotation productivity, mouldboard and differentiated tillage were equivalent, and in terms of economic and energy efficiency, the latter exceeded control. For all four variants of tillage in crop rotation, the highest energy efficiency coefficient was recorded for the annual application of 12 tons of manure per hectare of arable land + $N_{95}P_{82}K_{72}$

Key words**:** *tillage, fertilizers, crop, crop rotation, yield*

INTRODUCTION

Due to the need to reduce the anthropogenic load on land resources, the intensity of erosion and deflation and other degradation processes, energy intensity of agricultural products, there is a problem of developing and implementing resource- and moisture-saving soil protection systems of mechanical tillage under conditions of gradual climate deterioration.

The question of expediency and efficiency of different systems of mechanical tillage in agriculture of Ukraine remains the most debatable, ambiguous and controversial during the XIX-XXI centuries [13, 14].

At the end of the last century, some domestic scientists advocated the complete abandonment of the use of plows by replacing them with disc, flat, chisel and other mouldboardless tools [3, 21, 5, 22, 8, 2, 23].

However, as it turned out, constant mouldboardless tillage leads, first of all, to the deterioration of phytosanitary conditions of agrophytocenoses (despite the widespread use of pesticides), as well as to the differentiation of the arable soil layer (to which different crops respond differently) by indicators and conditions of fertility, local acidification of soils, reducing the depth of the root layer and the duration of the aftereffect of manure, compaction of the lower parts of the arable layer [15, 6, 7, 12, 11, 19].

Today, most domestic researchers prefer a differentiated (combined) system of basic

tillage, which provides a scientific combination of different methods, measures and means of its implementation at different depths depending on agrophysical, agrochemical and biological indicators of soil fertility, biological features of cultivated crops, climatic, weather and landscape conditions, resource and energy potential of farms to ensure the production of environmentally safe and economically reasonable competitive agricultural products with optimal agri-environmental efficiency [9, 16, 24, 20, 17, 18, 26].

On ordinary medium loam black soil of the Right Bank Steppe of Ukraine the highest agrotechnological effect in crop rotation was provided by a combination of plowing for row crops with "zero" cultivation for agricultural plants of conventional row sowing method, in which the level of profitability and energy efficiency factor on 74.6 and 44.0% higher, compared with different depth plowing [4].

On ordinary heavy loamy black soil of the Northern Steppe of Ukraine, mouldboard, differentiated and shallow (mulching) tillage systems in the five-field crop rotation were equivalent in terms of productivity, except for unfertilized options, where the latter was inferior to the first two by 5.5-7.5%. The highest economic efficiency under the mulching system – the level of profitability was 84-115%. During the mouldboard tillage, this figure decreased to 75-105%. In short crop rotations, the scientist recommends a differentiated system of cultivation on flat lands and mulching – on deflation-hazardous soils. The researcher proposes plowing for corn with reversible plows to a depth of 23-25 cm with differentiated tillage in crop rotation and flat-cutting tillage with tools CR-4,5 or CWRST-5,6 “Resident” at 14-16 cm for shallow tillage [28].

On the typical low-humus medium-loamy black soil in the typical grain ten-field crop rotation of the Forest-Steppe of Ukraine, among the studied main tillage systems, the most energy efficient was differentiated and mouldboard-mouldboardless. The latter one, which is recommended for production, involves plowing with a tiered plow in two fields of crop rotation for sugar beets, and for the rest of the crops – cultivation with flat and disk tools at different depths [27].

In Northern Steppe of Ukraine, the Institute of Agriculture of the steppe zone of NAAS offers plowing for corn and sunflower to a depth of 25-27 cm, and on erosion-hazardous lands – flat cultivation on ordinary low-humus black soil [25].

Kharkiv NAU recommends to the farms of the Left Bank Forest-Steppe and Northern Steppe: deep (not less than 25-27 cm) plowing once in three or four years for row crops, first of all sugar beet; to increase the share of chisel (mouldboardless) deep and medium tillage for the cultivation of legumes, spring cereals and sunflower to 30-50%; surface and shallow tillage with disc and combined implements for winter cereals, as well as partially for spring ear crops, especially when growing them after the late predecessors; direct sowing should be applied periodically and first of all under grain ear crops for harvesting them after late predecessors, with low weediness of fields and chemical weeding if necessary [20].

On typical deep black soil in the Right Bank Forest-Steppe of Ukraine the highest agrotechnical, economic and energy efficiency in fodder five-field crop rotation was reached at long shallow cultivation providing deep (on 30-32 cm) cultural plowing under fodder beets (where manure is applied), and under the rest of agrophytocenoses – peeling by 10-12 cm with heavy disc harrow and mouldboard cultivator [12].

A number of scientists propose a two-phase basic tillage, in which the first phase includes the preparation of the seedbed to the minimum depth and sowing of agricultural crops, the second – actually the main (mouldboardless) tillage to the full depth of the arable layer after sowing in the presence of weed seedlings or after their appearance in the early stages of organogenesis of the cultural component of agrophytocenoses [10].

On typical deep medium loamy black soil in LLC “Agro-firm Kolo” Skvyra district of Kyiv region, the highest profitability (74.3%) of grain ten-field crop rotation during 2011-2018 was obtained by mouldboard-mouldboardless tillage, which provided for plowing in two fields (under sugar beets and

sunflowers), and in the rest of the fields – different depths of mouldboardless hoeing. Under systematic disk tillage for all crop rotations to a depth of 8-10 cm, this indicator was lower on 14.2% [26].

Today the role of plowing in modern farming is being reconsidered, especially from the standpoint of agrophysical condition of soils. In particular, a fairly respectable generality of domestic agricultural scientists proves that plowing should be carried out with plows with plowshares or two-tiered plows only when the coefficient of structure of the upper soil layer (8-10 cm) is less than 0.76. Under plowing without plowshares, the arable layer is homogeneous, with plowshares – heterogeneous (lower – sprayed, upper – structured). Scientists point to a fundamentally important postulate of aerobic conditions in the upper and anaerobic in the lower parts of the arable layer, based on sufficient experimental material of Williams [29] and other well-known soil scientists. The task of swapping two layers of soil without any mixing (which is in principle unacceptable) can now be solved only by a plow, but it must be equipped with plowshares [1].

The purpose of the study was to establish the most effective combination of basic tillage and fertilizer systems, which provides 4.6 tons of dry matter, 6.4 tons of fodder units and 0.54 tons of digestible protein of marketable crop products at the highest economic and energy efficiency.

MATERIALS AND METHODS

The experimental work was performed on a typical deep low-humus medium-loam black soil in experimental field of Bila Tserkva National Agrarian University during 2018-2021 in a stationary field grain five-field crop rotation. Four systems of basic tillage (Table 1) and four systems of fertilizer (Table 2) in crop rotation were studied.

In the experiment threefold repetition was used. Repetitions on the area were placed systematically, continuously.

Plots with different tillage options (first order) were placed sequentially, systematically in one tier, and with fertilizer levels (second order) – sequentially in four tiers. The sown and registered area of the first order plots was 684 m^2 (9 × 76) and 448 m^2 (7 × 64), respectively, the second – 171 m^2 (9 × 19) and 112 m^2 (7 × 16). The area of each field without the surrounding protective strips was 7835.6 m^2 (73 × 103.1). The total number of elementary plots was 240, and the area under the experiment was 3.7 hectares.

Plowing was performed with a plow PPM-3-35, chisel (mouldboardless) tillage – with a deep cultivator DR-3.4, and disk (mouldboard) – with a heavy disc harrow HDH-3.0.

From fertilizers, semi-rotted manure (on straw litter) of cattle, ammonium nitrate, potassium salt, and simple granular superphosphate were applied. The crop was harvested by direct combining.

Table 1. Systems of basic tillage in crop rotation

Field No	Crop in crop rotation	Tillage*			
		mouldboard (control)	mouldboardless	mouldboard & mouldboardless (differentiated)	disking (continuous shallow)
		Depth (cm) and cultivation			
1	Soybean	16-18 (p.)	16-18 (d.t.)	16-18 (r)	10-12 (d.h.)
2	Winter wheat + white mustard on green manure	10-12 (d.h.)	10-12 (d.t.)	10-12 (d.h.)	10-12 (d.h.)
3	Sunflower	25-27 (p.)	25-27 (d.t.)	25-27 (p.)	10-12 (d.h.)
4	Spring barley + white mustard on green manure	10-12 (d.h.)	10-12 (d.t.)	10-12 (d.h.)	10-12 (d.h.)

Source: Authors' own results.

*Note: p. – plowing, d.h. – disc harrow, d.t. – deep tiller.

Table 2. Fertilizer systems under crops of field grain-plowing crop rotation

N of field	Crop rotation crops	Fertilizer level	Manure, t/ha	Mineral fertilizers, kg/ha a.s.												
				Total			Basic fertilizer			Under pre-sowing cultivation			Row fertilizer			Feeding N
				N	P	K	N	P	K	N	P	K	N	P	K	
1	Soybean	0														
		1		30	40	30		40	30	30						
		2		40	60	40		60	40	40						
		3		60	80	60		80	60	60						
2	Winter wheat	0														
		1		100	70	50	30	70	50							70
		2		125	90	70	30	90	70							95
		3		150	110	80	30	110	80							120
	White mustard on green manure	0														
		1		15	15	15	15	15	15							
		2		15	15	15	15	15	15							
		3		15	15	15	15	15	15							
3	Sunflo-wer	0														
		1	20	50	50	35	50	50	35							
		2	30	80	80	50	80	80	50							
		3	40	100	100	70	100	100	70							
4	Spring barley	0														
		1		50	40	40		40	40	50						
		2		60	50	50		50	50	60						
		3		70	60	60		60	60	70						
	White mustard on green manure	0														
		1		15	15	15	15	15	15							
		2		15	15	15	15	15	15							
		3		15	15	15	15	15	15							
5	Maize	0														
		1	20	120	90	100		80	100	120				10		
		2	30	140	100	120		90	120	140				10		
		3	40	150	120	130		110	130	150				10		
Per 1 ha of crop rotation		0														
		1	8	76	64	57	22	62	57	40				2		14
		2	12	95	82	72	28	80	72	48				2		19
		3	16	112	100	86	32	98	86	56				2		24

Source: Authors' own results.

RESULTS AND DISCUSSIONS

Soybean yield was the highest (on average 2.50 t/ha) under mouldboard tillage in crop rotation; under mouldboardless, differentiated and disk, it was respectively, 0.47, 0.13 and 0.39 t/ha or on 18.8, 5.2 and 15.4% lower (Table 3).

As the level of applied fertilizers increased, the difference in yield between cultivation options increased as well. Thus, in the unfertilized areas, fertilized with $N_{30}P_{40}K_{30}$, $N_{40}P_{60}K_{40}$ and $N_{60}P_{80}K_{60}$ grain was obtained

less, respectively, on 0.31, 0.43, 0.53 and 0.62 t/ha under chisel, 0.08, 0.12, 0.15 and 0.18 – mouldboard-mouldboardless, 0.26, 0.35, 0.42 and 0.54 t/ha under shallow cultivation than in the control. Yields of winter wheat under mouldboardless and disc tillage in crop rotation were significantly lower (on average on 0.59 and 0.49 t/ha, respectively), and under differentiated – insignificantly (0.20 t/ha) less than in the control, and as fertilizer rates increased, these differences became more pronounced. On unfertilized variants, with the application of $N_{100}P_{70}K_{50}$, $N_{125}P_{90}K_{70}$ and $N_{150}P_{110}K_{80}$, grain yield was lower on 0.43, 0.56, 0.63 and 0.1 t/ha under chisel cultivation, 0.12, 0.18, 0.23 and 0.27 – mouldboard-mouldboardless, 0.33, 0.46

Table 3. Crop yields under different tillage and fertilizer systems, t/ha

The main tillage in crop rotation	Fertilizer levels in crop rotation	Soybean	Winter wheat	Sunflower	Spring barley	Corn	White mustard for green manure	
							after winter wheat	after spring barley
Mouldboard (control)	0	1.12	2.73	1.21	2.37	4.82	9.86	8.83
	1	2.11	4.78	2.09	3.74	7.90	17.75	14.10
	2	2.96	6.35	2.98	4.78	9.73	21.88	18.26
	3	3.81	7.80	3.69	5.67	11.74	23.79	21.09
Mouldboardless (chisel)	0	0.81	2.30	0.96	2.05	4.28	8.63	7.50
	1	1.68	4.22	1.81	3.32	7.19	16.30	12.51
	2	2.43	5.72	2.62	4.29	8.85	20.21	16.47
	3	3.19	7.09	3.24	5.11	10.78	21.95	19.13
Differentiated	0	1.04	2.61	1.45	2.53	4.58	9.48	10.28
	1	1.99	4.60	2.42	3.87	7.59	17.26	15.44
	2	2.81	6.12	3.38	4.86	9.35	21.23	19.53
	3	3.63	7.53	4.14	5.73	11.32	22.98	22.28
Shallow (disk)	0	0.86	2.40	0.86	2.13	4.17	8.31	7.19
	1	1.76	4.32	1.66	3.41	7.05	15.96	12.22
	2	2.54	5.79	2.47	4.40	8.76	19.91	16.19
	3	3.27	7.19	3.11	5.25	10.64	21.66	18.89
$SD_{0.05}$		0.24	0.33	0.21	0.22	0.46	0.98	0.870.87

Source: Authors' own results.

The yield of sunflower seeds was significantly higher under differentiated (on average 0.36 t/ha) and significantly lower under mouldboardless (0.33 t/ha) and especially disk (0.46 t/ha) than under mouldboard tillage in crop rotation, where the average value of this indicator was 2.49 t/ha. On unfertilized plots, fertilized with 20 t/ha of manure + $N_{50}P_{50}K_{35}$, 30 t/ha of manure + $N_{80}P_{80}K_{50}$ and 40 t/ha of manure + $N_{100}P_{100}K_{70}$, oilseeds were collected, respectively, on 0.25, 0.28, 0.36 and 0.45 t/ha less than under chisel, on 0.35, 0.43, 0.51 and 0.58 – under disk cultivation and on 0.24, 0.33, 0.40 and 0.45 t/ha more under differentiated cultivation than in control. Thus, deep cultivation in crop rotation once during the rotation period and under this crop provided its highest yield, the average of which according to the experimental options reached 2.85 t/ha.

Yields of spring barley under chisel and shallow cultivation were on 0.45 and 0.34 t/ha (10.9 and 8.2%) lower, respectively, and under mouldboard-mouldboardless – on 0.11 t/ha (2.7%) higher than in the control. On unfertilized versions, fertilized with $N_{50}P_{40}K_{40}$, $N_{60}P_{50}K_{50}$ and $N_{70}P_{60}K_{60}$, this figure was, respectively, on 0.32, 0.42, 0.49 and 0.56 t/ha under mouldboardless and on 0.24, 0.33, 0.38 and 0.42 t/ha under disk tillage lower, and under differentiated – on 0.16, 0.13, 0.08 and 0.06 t/ha higher than in the control.

Yield of corn under chisel, mouldboard-mouldboardless and constant shallow tillage in crop rotation, compared with mouldboard, was, respectively, less on 0.77, 0.34 and 0.89 t/ha (9.0, 4.0 and 10.4%). Fertilizers increased the difference between cultivation options, which at the highest rate exceeded unfertilized areas in 1.7-1.8 times. Thus, on unfertilized variants, fertilized with 20 t/ha of manure + $N_{120}P_{90}K_{100}$, 30 t/ha of manure + $N_{140}P_{100}K_{120}$ and 40 t/ha of manure + $N_{150}P_{120}K_{130}$ corn grain was obtained less, respectively, on 0.54, 0.71, 0.88 and 0.96 t/ha under mouldboardless, 0.24, 0.31, 0.38 and 0.42 – differentiated and 0.65, 0.85, 0.97 and 1.10 t/ha under disk tillage, than in the control.

Regarding the collection of fodder units of

marketable products from each hectare of agrophytocenoses, crop rotations were in the following descending order: corn – 10.79 t/ha, winter wheat – 5.97; spring barley – 4.88; soybeans – 2.75; sunflower – 1.86.

As for the yield of digestible protein, the sequence of crops was as follows: soybeans – 0.615 t/ha; corn – 0.507; winter wheat – 0.434; sunflower – 0.343; spring barley – 0.282 t/ha.

Under both predecessors in the crop rotation, green mass of white mustard came to the soil significantly less than under chisel and disk tillage than in the control. Productivity of siderate crop under differentiated cultivation, in comparison with mouldboard tillage, was insignificantly lower (on 0.38-0.81 t/ha) in the link with winter wheat and significantly higher (on 1.19-1.45 t/ha) under its sowing after spring barley.

With the main production of agrophytocenoses of crop rotation from each hectare of arable land, it was received 4.00 tons of dry matter, 5.58 tons of feed units and 0.467 tons of digestible protein under mouldboard tillage, 3.55, 4.96 and 0.406, respectively – under chisel, 3.96, 5.49 and 0.464 – mouldboard-mouldboardless and 3.55 tons of dry matter, 4.97 tons of feed units and 0.407 tons of digestible protein under systematic shallow tillage (Table 4).

Taking into account the by-products of winter wheat and spring barley, the above indicators of crop rotation productivity were, respectively, 5.94, 6.29 and 0.483 tons under mouldboard tillage, 5.37, 5.62 and 0.421 – mouldboardless, 5.91, 6.21 and 0.481 – differentiated and 5.39, 5.65 and 0.423 tons under disk tillage.

The highest ratio of grain to straw was recorded under mouldboard tillage in crop rotation, which for winter wheat was 1,228, spring barley – 1,096, that is on 4.5 and 6.8% more than under chisel, 1.5 and 1.8% – mouldboard-mouldboardless, 2.9 and 5.8% – shallow tillage.

Table 4. Collection of dry matter of crops and crop rotation productivity under different systems of tillage and fertilizers, t/ha

The main tillage in crop rotation	Fertilizer levels in crop rotation	Soybean (grain)	Winter wheat (grain + straw)	Sunflower (seeds)	Spring barley (grain + straw)	Corn (grain)	Crop rotation productivity	
							taking into account the by-products of cereals	taking into account only the basic products of all crops
Mouldboard (control)	0	0.98	5.15	1.02	4.25	4.20	3.12	2.12
	1	1.85	9.07	1.76	6.78	6.89	5.27	3.57
	2	2.60	12.18	2.52	8.75	8.48	6.91	4.64
	3	3.34	15.10	3.11	10.50	10.24	8.46	5.66
Mouldboardless (chisel)	0	0.71	4.45	0.81	3.81	3.73	2.70	1.80
	1	1.47	8.23	1.53	6.26	6.27	4.75	3.15
	2	2.13	11.22	2.21	8.13	7.72	6.28	4.14
	3	2.80	14.03	2.73	9.75	9.40	7.74	5.09
differentiated	0	0.91	4.95	1.22	4.59	3.99	3.13	2.11
	1	1.75	8.83	2.04	7.09	6.62	5.27	3.54
	2	2.46	11.86	2.85	8.98	8.15	6.86	4.58
	3	3.18	14.70	3.49	10.70	9.87	8.39	5.59
Shallow (disk)	0	0.75	4.59	0.73	3.93	3.64	2.73	1.80
	1	1.54	8.33	1.40	6.38	6.15	4.76	3.15
	2	2.23	11.28	2.08	8.28	7.64	6.30	4.14
	3	2.87	14.14	2.62	9.96	9.28	7.77	5.10

Source: Authors' own results.

On unfertilized areas, fertilized with 8 tons of manure + $N_{76}P_{64}K_{57}$, 12 tons of manure + $N_{95}P_{82}K_{72}$ and 16 tons of manure + $N_{112}P_{100}K_{86}$ per hectare of arable land, crop rotation productivity was 2.12, 3.57, 4.64 and 5.66 tons of dry matter of marketable products under mouldboard tillage in crop rotation; 1.80, 3.15, 4.14 and 5.09 tons – mouldboardless; 2.11, 3.54, 4.58 and 5.59 tons – differentiated; 1.80, 3.15, 4.14 and 5.10 tons under disk tillage in crop rotation ($SD_{0.05}$ = 0.24 tons). Taking into account the by-products of cereals (straw of winter wheat and spring barley), the collection of feed units for

fertilizer options was, respectively, 3.35, 5.62, 7.29 and 8.90 tons under mouldboard tillage; 2.87, 5.01, 6.55 and 8.06 – chisel; 3.32, 5.56, 7.18 and 8.76 – mouldboard-mouldboardless; 2.89, 5.02, 6.58 and 8.09 tons under shallow tillage in crop rotation ($SD_{0.05}$ = 0.39 tons), and the yield of digestible protein was, respectively, 0.245, 0.424, 0.565 and 0.699 tons under mouldboard tillage; 0.202, 0.367, 0.496 and 0.619 – mouldboardless, 0.246, 0.422, 0.561 and 0.693 – differentiated; 0.204, 0.368, 0.499 and 0.621 tons under disk tillage ($SD_{0.05}$ = 0.21 tons).

The best indicators of economic efficiency were obtained under mouldboard-mouldboardless tillage in crop rotation, in which the cost of growing crops and the cost of one ton of feed units, respectively, were on 2.2 and 1.2% lower, and the cost of gross output, net profit and profitability, respectively, on 2.2, 9.1 and 6.9% higher than in the control. Under constant shallow tillage, economic efficiency indicators turned out to be the worst: total costs for growing crops, the value of gross output, profit and profitability, respectively, on 5.2, 11.4, 23.5 and 9.6% lower, and the cost was 6.3% higher than mouldboard tillage in crop rotation.

The first four indicators listed above were, respectively, on 9.5, 11.9, 17.1 and 3.8% higher, and the cost was on 1.0% lower under mouldboard than disk tillage in crop rotation (Table 5).

Table 5. Economic efficiency of different systems of basic tillage and fertilization in crop rotation

The main tillage in crop rotation	Fertilizer levels in crop rotation	Total costs, thousand UAH/ha	Cost of gross output, thousand UAH/ha	Cost of 1 t of fodder units, thousand UAH	Conditionally net profit, thousand UAH/ha	Profitability, %
Mouldboard (control)	0	11.42	15.08	3.85	3.66	32.0
	1	16.85	25.48	3.37	8.63	51.2
	2	26.39	42.88	4.09	16.49	62.5
	3	40.41	62.44	5.13	22.03	54.5
Mouldboardless (chisel)	0	10.34	12.80	4.07	2.46	23.8
	1	15.70	22.32	3.55	6.62	42.2
	2	25.03	38.11	4.34	13.08	52.2
	3	39.02	56.05	5.50	17.03	43.6
Differentiated	0	10.84	15.13	3.69	4.29	39.5
	1	16.33	25.93	3.32	9.60	58.8
	2	25.91	44.05	4.08	18.14	70.0
	3	39.89	63.72	5.15	23.83	59.7
Shallow (disk)	0	9.75	12.74	3.82	2.99	30.7
	1	14.85	21.96	3.35	7.11	47.9
	2	24.31	37.88	4.20	13.57	55.8
	3	37.09	55.88	5.22	18.79	50.7

Source: Authors' own results.

The lowest cost of one ton of fodder units in all cultivation options was recorded under the application of 8 tons of manure per hectare of arable land + $N_{76}P_{64}K_{57}$, and the highest profitability – under fertilizing with 12 tons of manure + $N_{95}P_{82}K_{72}$. These figures were respectively 3.37 thousand UAH and 62.5% under mouldboard tillage, 3.55 and 52.2 – chisel, 3.32 and 70.0 – mouldboard-mouldboardless, 3.35 thousand UAH and 55.8% under shallow tillage in crop rotation.

The highest energy costs for growing crop products were recorded under shelf tillage in crop rotation – 42.8 GJ/ha, under mouldboardless, differentiated and disk, they were, respectively, on 3.3, 4.2 and 7.7% lower (Table 6).

It should be noted that chisel hoeing is a less energy-intensive measure than plowing, but further additional operations with heavy tillage implements in the crop rotation cycle offset this advantage. And the direct operating costs on mechanical tillage under the

inclusion of energy equivalents of pesticides (6-8%) and fertilizers (up to 60%) use are currently up to 5-8% [14].

Table 6. Energy efficiency of different systems of basic tillage and fertilization in crop rotation

The main tillage in crop rotation	Fertilizer levels in crop rotation	Total energy consumed, GJ/ha	Energy output with yield, GJ/ha		Energy efficiency ratio	
			main products	all products	main products	all products
Mouldboard (control)	0	23.9	37.0	75.2	1.5	3.1
	1	32.4	62.3	140.8	1.9	4.3
	2	46.8	137.5	273.5	2.9	5.8
	3	68.1	173.0	330.0	2.5	4.8
Mouldboardless (chisel)	0	22.8	30.5	63.8	1.3	2.8
	1	31.2	55.0	124.2	1.8	4.0
	2	45.5	122.8	244.0	2.7	5.4
	3	66.3	155.1	296.7	2.3	4.5
Differentiated	0	22.3	37.5	77.2	1.7	3.5
	1	30.5	63.0	142.3	2.1	4.7
	2	44.8	137.4	276.0	3.1	6.2
	3	66.3	175.7	335.2	2.7	5.1
Shallow (disk)	0	21.2	30.2	63.3	1.4	3.0
	1	29.6	55.2	124.9	1.9	4.2
	2	43.5	121.2	243.4	2.8	5.6
	3	63.7	155.0	296.0	2.4	4.6

Source: Authors' own results.

The coefficients of energy efficiency of marketable and all crop products under chisel tillage in crop rotation were 9.1 and 6.7%, respectively, under shallow – on 4.5 and 4.4% lower, and under mouldboard-mouldboardless on 9.1 and 8.9 % higher than in the control. In all studied variants of tillage, the energy efficiency coefficient reached the highest values with the application of 12 tons of manure per hectare of arable land + $N_{95}P_{82}K_{72}$. On average, according to the experiment, the coefficient of energy efficiency of the main and all agricultural products was, respectively, 2.2 and 4.5 under mouldboard tillage in crop rotation, 2.0 and 4.2 – mouldboardless, 2.4 and 4.9 – mouldboard-mouldboardless, 2.1 and 4.4 under disk tillage.

Thus, in terms of crop rotation productivity, mouldboard and differentiated cultivation were almost equivalent, and in terms of economic and energy efficiency, the advantage in most cases was under mouldboard-mouldboardless tillage, which involves deep cultivation in only one field, and in other fields – tillage with a disc harrow and a cultivator.

Under chisel and shallow tillage these indicators worsen.

CONCLUSIONS

Yields of soybeans, winter wheat and white mustard and corn were higher under mouldboard, but sunflower, spring barley and white mustard – higher under differentiated tillage in crop rotation.

All crops significantly reduced this figure under chisel and constant shallow tillage.

Crop rotation productivity was almost at the same level under mouldboard and mouldboard-mouldboardless tillage, under chisel and disk it was significantly lower.

The highest indicators of economic and energy efficiency were provided by the main differentiated tillage of typical black soil in

grain five-field crop rotation, in which deep cultivation of 25-27 cm was carried out in one field (for row-crop, where manure was applied), and in the rest of the fields – disking and chiselling.

The most economically and energy-efficient norm was the application of 12 tons of manure per hectare of arable land + $N_{95}P_{82}K_{72}$.

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