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ECONOMIC AND ENERGY EFFICIENCY OF PRIMARY TILLAGE AND FERTILISATION SYSTEMS IN FIVE-FIELD CROP ROTATION OF THE RIGHT-BANK FORESTSTEPPE OF UKRAINE

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Abstract

According to the greening index, the zero level of fertilization in crop rotation corresponds to biological agriculture, the first level to ecological agriculture, and the second and third levels to its biologisation. According to the ecological classification of cropping systems, the first and second levels of fertilization ensure an increasing, and the third intensive level of greening of the agricultural sector. The yield of crops in the crop rotation is significantly reduced in the case of chisel disc and disking tillage. Differentiated tillage slightly reduces this indicator in peas, corn, white mustard in the link with legumes and slightly increases in winter wheat and buckwheat. At the same time, the yield of white mustard increases in the link with buckwheat, but only in fertilized areas. In terms of crop rotation productivity, the mouldboard and differentiated tillage are equivalent, while the chisel disc and disking tillage are significantly inferior to the control. The highest indicators of economic and energy efficiency were obtained with differentiated tillage with the application of 6 tons of manure + $N_{98}P_{66}K_{92}$ *per hectare of crop rotation. It is recommended that in a five-field grain crop rotation, ploughing (mouldboard) should be carried out only for corn (to a depth of 25-27 cm), differentiated tillage for peas (to a depth of 18-20 cm), and disking tillage should be used for other crops (to a depth of 6-12 cm) with the application of 6 tons of manure +* $N_{98}P_{66}K_{92}$ *per hectare of arable land and the use of non-marketable products as organic fertilizer*

Key words: *crop rotation, tillage, fertilization, crops, yield,* marketable products, non-marketable products, *economic efficiency, energy efficiency*

INTRODUCTION

Today, there are many requirements for mechanical tillage: it must be soil-protective, moisture-saving, anti-erosion, soil-forming, resource-saving, and must provide for the preservation of soil ecological functions, in particular, bio-ecological, bioenergy, hydrological, hydrogeological, biogeochemical, gas-atmospheric and biogeocenotic functions [33]. Scientists point out that the ecological functions of the soil related to the regulation of gas exchange, moisture exchange and heat transfer by mechanical tillage and fertilizer application ensure the maintenance of biodiversity and ultimately life on the planet [14, 15].

Until the early 20th century, the depth of main tillage in Ukraine increased and then differentiated depending on the biological characteristics of agricultural plants and soil and climatic conditions. In the middle of the first half of the 20th century, the optimal ploughing depth for chernozems was 18-22 cm, and in some cases 25-27 cm [11, 16].

From the 1930s to the 1950s, the main tillage method in Ukrainian agriculture was ploughing with ploughs with skimmers to a depth of at least 20-22 cm. The main purpose of tillage during this period was to create a strong, structured, cultivated topsoil to a depth of at least 20 cm, in the lower part of which the most favourable conditions for moisture and structure formation were created [17].

In 1952, for the first time in the Soviet Union, Taras Maltsev abandoned ploughing. He made a moldboardless plough, which he used in a four-field crop rotation to deeply cultivate only the fallow fields, and to disc the rest by 7-8 cm [18].

Today, most scientists suggest ploughing once every 3-5 years, mainly for row crops, and for other crops, conducting moldboardless cultivation with flat cutters, disking, peeling to different depths [19].

Scientists recommend cultural ploughing when the coefficient of structure of the upper (0-10 cm) soil layer is below 0.67 (according to the Savvinov method)[9]. The principle is the mutual movement of two layers of soil (upper and lower) by ploughing [9].

The plough without skimmers can be used to incorporate lime and manure into the soil [10]. In other cases, cultivated ploughing with skimmers is effective, even on weed-free fields, as it creates a heterogeneous tilts layer. A plough without skimmers only mixes the top (de-structured) and bottom (insufficiently structured) layers of soil to form a homogeneous cultivated layer [1].

Most scientists propose to use a differentiated system of basic tillage in crop rotations, which involves a scientifically based combination of methods and measures of mechanical impact on different soil depths, taking into account the biological characteristics of agricultural plants, soil differences, climatic conditions, fertilization systems[14, 16, 1, 10].

Main cultivation should primarily ensure increased labour productivity, environmentally sound land use, soil protection from degradation processes, efficient use of water resources and improvement of recreational properties of landscapes, as its impact on the productivity of agrophytocenoses is almost the same, and the soil nutrient regime and phytosanitary condition are optimized by the use of fertilizers and pesticides, respectively [26]. However, our recent research indicates the opposite: agrophytocenosis yields and crop rotation productivity can significantly depend on the main tillage systems [20, 21, 22, 23].

The results of research by other domestic scientists also convincingly prove this conclusion. On the typical deep black soil of "Agrofirma Kolos" of Kyiv region (Ukraine) in a stationary field grain crop rotation of ten plots, the highest efficiency was provided by the system of shelfless tillage, in which deep ploughing was carried out for sunflower and sugar beet, shallow shelfless loosening for winter wheat after corn for silage and soybeans and chiselling for other crops [3].

The most effective system of shelfless tillage in the conditions of the Right-Bank Steppe of Ukraine was the one that provides for a combination of ploughing for row crops with "zero" tillage for agrophytocenoses of the usual row seeding method in the crop rotation. Research by the Kirovograd Institute of Agricultural Production (Ukraine) has given grounds to recommend winter wheat production: after black fallow, no-till cultivation by 18-22 cm, corn for silage – disking or "zero" cultivation (for ploughing under the predecessor); for sugar beet – ploughing by 28-30 cm (for flat-cutting by 18-22 cm for the winter wheat predecessor); for spring barley - 20-22 cm flat-cutting (with 28-30 cm ploughing under the sugar beet predecessor); for corn – 25-27 cm ploughing; for peas – 18-22 cm ploughing or zero tillage (with 25-27 cm ploughing under the corn predecessor; for sunflower – 22-25 cm ploughing in dry years and minimal tillage in wet years [4].

Also, in the Forest-Steppe of Ukraine, a differentiated system of primary tillage is proposed, which provides for periodic (every 3-4 years) deep ploughing (25-27 cm) for row crops, primarily sugar beet; deep and medium moldboardless tillage for legumes, sunflower and spring grain crops; shallow or surface tillage with combined and disc tools for winter cereals; periodic direct sowing for cereals under the condition of chemical weeding, low weediness of fields and late harvesting of predecessors [27].

In the five-field stationary crop rotation of the Institute of Agriculture of the Steppe Zone (Ukraine), shelf, differentiated and shallow (mulching) systems of cultivation of ordinary heavy loamy chernozem are equivalent in terms of arable land productivity, and the latter has an advantage in terms of economic and energy efficiency [31].

The highest agrotechnical, economic and energy efficiency in field grain-tilled crop rotation of the Right-Bank Forest-Steppe of Ukraine under industrial, ecological and biological farming systems was provided by the shelfless main tillage of typical chernozem. Scientists recommend ploughing with a tiered plough every 4-5 years of crop rotation and using disc and flat-cut tillage between ploughing [29].

The Odesa State Agricultural Research Station (Ukraine) recommends a differentiated system of basic tillage of southern black soil in short rotation crop rotations in the Southern Steppe of Ukraine [7].

In the stationary experiments of the Cherkasy State Agricultural Experimental Station (Ukraine) during 1975-2015, the highest grain yields were obtained with systematic ploughing - 6.45 and 8.19 t/ha in crop rotations with perennial grasses and peas, respectively; with no-till cultivation, the decrease in this indicator is insignificant, and with surface cultivation - significant. The highest yield of winter wheat (4.89-4.95 t/ha) was obtained in a crop rotation with perennial grasses under shallow tillage, and under moldboardless tillage it was lower than under ploughing [5].

In a typical five-field rotation (20% each of perennial and annual grasses and row crops, the remaining 40% of cereals), the highest efficiency indicators were achieved with differentiated tillage, with deep ploughing once per rotation and shallow (10-12 cm) chernozem tillage in the other years, using a typical stubble cultivator and disc harrow [12].

It is important to study the systems of basic cultivation and fertilisation, and their agrotechnical, economic and energy evaluation are priority areas in modern approaches to agricultural production.

The aim of the study was to determine the optimal combination of tillage and fertilization systems for typical chernozem, which would ensure the best indicators of its structural and phytosanitary condition, crop rotation productivity at the level of 10 t/ha of dry matter, 8 t/ha of fodder units and 5.5 t/ha of digestible protein of the marketable and non-marketable products of agrophytocenoses.

MATERIALS AND METHODS

The studies were performed on a typical deep low-humus medium loam black soil of experimental field of Bila Tserkva National Agrarian University during 2020-2022 in a stationary a five-field grain crop rotation, where four systems of basic tillage (Table 1).

Table 1. Systems of basic tillage in crop rotation

№ field	Crop	Tillage*			
		mouldboard (control)	chisel disc	differentiated (mouldboard, chisel & mouldboardless)	disking (continuous shallow)
		Depth (cm) and cultivation			
1	Peas	18-20 (p.)	18-20 (*d.r.*)	18-20 (*d.r.*)	10-12 (d.h.)
2	Winter wheat	8-10 (d.h.)	8-10 (d.h.)	8-10 (d.h.)	8-10 (d.h.)
	White mustard on green manure	10-12 (d.h.)	10-12 (d.h.)	10-12 (d.h.)	10-12 (d.h.)
3	Corn	25-27 (p.)	25-27 (*d.r.*)	25-27 (p.)	10-12 (d.h.)
4	Buckwheat	10-12 (d.h.)	10-12 (*d.r.*)	10-12 (*d.r.*)	10-12 (d.h.)
5	Winter wheat	6-8(d.h.)	6-8 (d.h.)	6-8 (d.h.)	6-8 (d.h.)
	White mustard for green manure	10-12 (d.h.)	10-12 (d.h.)	10-12 (d.h.)	10-12 (d.h.)

**Note: p. – plowing, d.h. – disc harrow, d.r.* – deep ripper.
Source: Authors' own results.

Four fertilization systems were also studied : 0 – without fertilizers, 1 –6 t/ha of manure $+N_{64}P_{54}K_{58}$, 2 – 6 t/ha of manure + $N_{98}P_{66}K_{92}$, 3 – 6 t/ha of manure + $N_{126}P_{82}K_{116}$ (Table 2).

Table 2. Fertilization systems for crop rotation

№ field	Crop	Fertilizer level	Manure, t/ha	Mineral fertilizer's, kg/ha (active ingredient)									
				Total			Basic fertilizer		For pre-sowing cultivation	Row fertilization			Fertilizing with nitrogen
				N	P	K	P	K	N	N	P	K	N
1	Peas	0											
		1		30					30				
		2		30	30	30	30	30	30				
		3		30	30	50	30	50	30				
2	Winter wheat	0											
		1		60	60	60	60	60					60
		2		90	60	90	60	90					90
		3		120	60	90	60	90					120
	White mustard on green manure	0											
		1		30	30	30	30	30	30				
		2		60	30	60	30	60	60				
		3		80	60	80	60	80	80				
3	Corn	0											
		1	30	60	60	60	50	50	50	10	10	10	
		2	30	90	90	90	75	75	75	15	15	15	
		3	30	110	110	110	90	90	90	20	20	20	
4	Buckwheat	0											
		1		30	30	30	30	30	30				
		2		50	30	50	30	50	50				
		3		70	30	70	30	70	70				
5	Winter wheat	0											
		1		80	60	80	60	80					80
		2		110	60	80	60	80					110
		3		140	60	100	60	100					140
	White mustard on green manure	0											
		1		30	30	30	30	30	30				
		2		60	30	60	30	60	60				
		3		80	60	80	60	80	80				

Source: Authors own results.

In the experiment, threefold repetition was placed completely on the area, plots of the first order (tillage system) – sequentially in one tier, the second (fertilizer rates) – sequentially in four tiers. The sown area is 684 (9×76) and 171 (9×19) m², respectively, and the recorded area is 448 (7×64) and 112 (7×16) m². The area of one field without protective strips is 7835.6 m² (76×103.1), and the total area under the experiment is 3.7 hectares. The number of elementary plots in the experiment was 240. As organic fertilizers, we used by-products of agrophytocenoses, green mass of post-harvest white mustard and semi-rotted cattle manure, and as mineral fertilizers– ammonium nitrate, simple granular superphosphate and potassium salt. The soil structure was determined by the method of Igor Baksheev [30], accounting for pests and diseases according to the methods [2], weediness of crops by the quantitative weight method [24], humus balance by the method proposed Igor Pokotylo et al [13].

RESULTS AND DISCUSSIONS

In general, in the crop rotation during the vegetation of agricultural plants, the content of agronomically valuable water-resistant aggregates in the soil layers 0-10, 10-20, 20-30 and 0-30 cm was for mouldboard 65.3; 65.8, 66.2 and 65.8%, for chisel disc tillage - 61.0, 66.9, 68.4 and 65.5, 65.4; differentiated tillage - 66.2, 67.1 and 66.2; disc tillage - 60.2, 66.5, 68.4 and 65.1%, respectively. Thus, under chisel-disc and disc tillage there is a slight deterioration in the structural state of the arable layer (0-30 cm) of typical chernozem. Under the second and fourth tillage options, the structure of the upper (0-10 cm) soil layer was significantly lower by 4.3 and 5.1%, the middle (10-20 cm) layer was lower by 1.1 and 0.7%, and the lower (20-30 cm) layer was lower by 2.2% than under the control. In the soil layers of 0-10, 10-20, 20-30 and 0-30 cm, this indicator is 0.1, 0.4, 0.9 and 0.4% higher, respectively, for differentiated than for mouldboard tillage (Table 3).

Table 3. Crop yields in five-field crop rotation, t/ha

Tillage	Fertilizer level	Crop					White mustard as a green fertilizer in a link with	
		peas	winter wheat	corn	buckwheat	winter wheat	peas	buckwheat
mouldboard (control)	0	2.16	2.66	3.18	1.23	2.24	10.45	9.78
	1	2.94	4.84	5.77	1.97	4.26	15.16	15.61
	2	3.41	6.25	7.64	2.45	5.66	17.78	18.36
	3	3.69	6.87	8.39	2.70	6.29	18.89	19.61
chisel disc	0	1.92	2.33	2.64	0.98	1.83	9.92	10.21
	1	2.66	4.45	5.09	1.69	3.76	14.55	16.18
	2	3.11	5.80	6.85	2.14	5.11	17.04	18.93
	3	3.36	6.37	7.54	2.35	5.71	18.07	20.36
differentiated (mouldboard, chisel & mouldboardless)	0	2.05	2.87	2.90	1.31	2.36	10.10	10.42
	1	2.81	5.01	5.55	2.09	4.41	14.72	16.49
	2	3.26	6.40	7.46	2.60	5.84	17.22	19.32
	3	3.53	6.98	8.23	2.87	6.49	18.30	20.72
disking (continuous shallow)	0	1.85	2.21	2.13	0.85	1.71	9.47	8.89
	1	2.59	4.36	4.89	1.62	3.65	14.07	14.57
	2	3.01	5.69	6.89	2.15	4.98	16.58	17.20
	3	3.26	6.24	7.74	2.42	5.54	17.62	18.38
SD_{05}		0,21	0.31	0.44	0.24	0.36	0.91	0.82

Source: Authors own results.

The level of greening of the agricultural sector is assessed by two indicators: the rate of organic fertilizer application and the greening index [29, 32]. The latter is calculated by dividing the total amount of active ingredient of fertilizer (kg NPK) by the mass of organic matter (t) entering the soil, which was 10, 22, 25 and 27 t under zero, first, second and third fertilization systems, respectively, and the index of greening of agriculture was 0, 8, 10 and 12. According to this indicator the zero fertilization system corresponds to biological fertilization and the first one to ecological farming, the second and third to its biologisation [28]. According to the ecological classification of cropping systems [8, 25, 6] the first and second fertilizer systems ensure an increasing and intensive level of greening in the industry.

In winter wheat, corn and buckwheat, the highest ratio of marketable to non-marketable products was observed in disking tillage, slightly lower in chisel-disc tillage, and the lowest in the control. In peas, this indicator is the lowest for ploughing and the highest for differentiated cultivation. For mouldboard, chisel-disc, differentiated and disking tillage, it was 1.296; 1.248 for winter wheat after peas; 1,311 and 1.288, peas – 1.240; 1.278; 1.255 and 1.290, corn – 1.465; 1.555; 1.492 and 1.583, buckwheat – 2.516; 2.661; 2.563 and 2.760, in winter wheat after buckwheat – 1.271; 1.292; 1.284 and 1.309.

With an increase in the fertilizer rate, the ratio of marketable to non-marketable products increases in all tillage options.

Thus, under the zero, first, second and third fertilization systems of differentiated cultivation plots, this indicator was 1.184, 1.288, 1.331 and 1.332 for peas; 1.331 and 1.442, winter wheat after peas – 1.222; 1.247; 1.267 and 1.285, corn – 1.409; 1.477; 1.501

and 1.580, buckwheat – 2.402; 2.498; 2.605 and 2.748 in winter wheat after buckwheat – 1.267; 1.278; 1.290 and 1.299. The yields of the main crops of the crop rotation are significantly reduced under moldboard and disc tillage. Under differentiated cultivation, this indicator is slightly reduced in peas, corn, white mustard and slightly increased in winter wheat and buckwheat (Table 3). The yields of peas were 3.05, 2.76, 2.91 and 2.68 t/ha under the mouldboard, chisel disc, differentiated and disking, 5.16, 4.74, 5.32 and 4.63 t/ha of winter wheat after peas, 6.25; 5.53, 6.04 and 5.41 t/ha, buckwheat – 2.09, 1.79, 2.22 and 1.76 t/ha, winter wheat after buckwheat – 4.61, 4.10, 4.78 and 3.97 t/ha, white mustard in a link with peas – 15.57, 14.90, 15.09 and 14.44 t/ha, white mustard in a link with buckwheat – 15.84, 16.42, 16.74 and 14.76 t/ha. Under moldboard tillage, the yield of green manure decreases in the link with peas and increases in the link with buckwheat, but these deviations from the control did not reach statistically significant values. The difference in yields between the control and the rest of the experimental treatments with increasing fertilizer rates increased in white mustard (in the link with peas), peas and winter wheat after buckwheat; in winter wheat after peas, this was observed only in the second and fourth treatments.

Under the zero, first, second and third fertilization systems, the decrease in maize grain yield was 0.54, 0.68, 0.79 and 0.85 t/ha under the chisel disc, 0.28, 0.22, 0.18 and 0.16 under the differentiated cultivation, 1.05, 0.88, 0.75 and 0.65 t/ha under the disking; legumes – 0.24; 0.28, 0.30 and 0.33 in the second variant of cultivation, 0.11, 0.13, 0.15 and 0.16 in the third, 0.31, 0.35, 0.40 and 0.43 in the fourth; mustard in the link with peas – 0.53, 0.61, 0.74 and 0.82 in the second variant, 0.35, 0.44, 0.56 and 0.59 in the third, 0.98, 1.09, 1.20 and 1.27 t/ha in the fourth variant of soil tillage. White mustard in the link with buckwheat under zero, first, second and third fertilization systems increased the yield by 0.43, 0.57, 0.68 and 0.75 t/ha under chisel disc, 0.64, 0.88, 0.96 and 1.10 under differentiated tillage and decreased it by 0.89, 1.04, 1.16 and 1.23 t/ha under disking tillage. The yield of buckwheat decreased by 0.25, 0.28, 0.31 and 0.35 t/ha under the second and by 0.38, 0.35, 0.30 and 0.28 t/ha under the fourth cultivation options, respectively, and increased by 0.08, 0.12, 0.15 and 0.17 t/ha under the third cultivation option.

Table 4. Non-marketable yield and crop rotation productivity under different tillage and fertilization systems, t/ha

Tillage	Fertilizer level	Crop					Crop rotation productivity, dry matter	
		peas	winter wheat	corn	buckwheat	winter wheat	marketable products	marketable and non-marketable products
mouldboard (control)	0	2.53	3.22	4.39	2.92	2.81	1.98	4.48
	1	3.74	5.93	8.35	4.82	5.39	3.42	7.84
	2	4.49	7.82	11.39	6.29	7.23	4.40	10.22
	3	5.25	8.74	12.90	7.21	8.10	4.83	11.43
chisel disc	0	2.17	2.91	3.93	2.43	2.34	1.68	3.84
	1	3.28	5.64	7.84	4.27	4.84	3.05	7.10
	2	3.95	7.47	10.81	5.88	6.64	3.98	9.41
	3	4.57	8.33	12.13	6.79	7.46	4.38	10.52
differentiated (mouldboard, chisel & mouldboardless)	0	2.43	3.51	4.09	3.15	2.99	1.98	4.54
	1	3.62	6.25	8.20	5.22	5.64	3.44	7.99
	2	4.34	8.11	11.20	6.77	7.53	4.42	10.37
	3	5.09	8.96	13.00	7.89	8.43	4.86	11.65
disking (continuous shallow)	0	2.16	2.79	3.23	2.18	2.21	1.51	3.50
	1	3.20	5.59	7.68	4.27	4.77	2.96	6.95
	2	3.96	7.37	11.03	6.14	6.53	3.93	9.39
	3	4.67	8.22	12.72	7.23	7.31	4.36	10.62
SD_{05}		0.25	0.29	0.40	0.35	0.36	0.27	0.44

Source: Authors own results.

Table 5. Efficiency of the studied systems of basic tillage and fertilization of typical chernozem

Tillage	Fertilizer level	Economic efficiency					Energy efficiency				
		Expenses, thousand UAH /ha	Cost of production, thousand UAH/ ha	Cost per ton of feed units, UAH thousand.	net profit, thousand UAH/ha	Profitability, %.	energy consumption, GJ/ha	Energy yield with harvest, GJ/ha		Energy efficiency ratio	
								marketable products	marketable and non-marketable products	marketable products	marketable and non-marketable products
mouldboard (control)	0	12.35	14.81	3.43	2.46	19.9	33.8	48.3	102.7	1.4	3.0
	1	20.32	29.19	3.23	8.87	43.6	44.8	88.3	202.2	2.0	4.5
	2	25.65	40.90	3.14	15.25	59.4	55.5	160.5	318.7	2.9	5.7
	3	29.32	44.34	3.24	15.02	51.2	69.5	166.9	353.8	2.4	5.1
chisel disc	0	11.86	13.70	3.85	1.84	15.5	31.8	40.0	89.0	1.3	2.8
	1	21.04	27.77	3.71	6.73	32.0	37.7	67.1	154.9	1.8	4.1
	2	25.32	38.13	3.39	12.81	50.6	41.1	108.5	217.9	2.6	5.3
	3	29.36	41.19	3.55	11.83	40.3	57.2	134.4	282.0	2.4	4.9
differentiated	0	11.81	15.14	3.28	3.33	28.2	32.1	49.4	105.8	1.5	3.3
	1	19.75	29.90	3.12	10.15	51.4	43.2	89.9	208.7	2.1	4.8
	2	25.24	42.48	3.07	17.14	67.9	54.2	161.6	317.7	3.0	5.9
	3	29.22	45.70	3.20	16.48	56.4	67.0	168.1	346.8	2.5	5.2
disking (continuous shallow)	0	9.86	11.50	3.64	1.64	16.6	30.1	36.8	80.7	1.2	2.7
	1	18.70	25.23	3.39	6.53	34.9	36.5	62.8	146.4	1.7	4.0
	2	23.71	36.41	3.20	12.70	53.6	40.9	106.4	215.6	2.6	5.3
	3	27.89	39.60	3.36	11.71	42.0	56.9	132.5	278.1	2.3	4.9

Source: Authors own results.

The yield of pea and winter wheat (after both predecessors) is significantly lower in chisel disc and disking tillage than in the control. Under differentiated tillage, there is a slight decrease in this indicator in legumes and an increase in winter wheat after buckwheat; in winter wheat after peas, this indicator increased slightly (by 0.22 t/ha) only in areas with the highest fertilizer rate (table 4).

The yield of non-marketable products of corn and buckwheat is significantly lower on the second than on the first variant of tillage.

The yield of buckwheat straw only on fertilized plots was significantly higher under differentiated than under chisel disc tillage and the growth was insignificant on unfertilized plots.

Under disc cultivation, at zero and first fertilization levels, this figure was 0.74 and 0.55 t/ha lower than in the control, while at the second and third fertilization levels this difference was insignificant.

The output of non- marketable products per hectare of arable land in crop rotation under mouldboard tillage was 2.50, 4.42, 5.82 and 6.60 t/ha, chisel disc tillage – 2.16, 4.05, 5.43 and 6.14 t/ha; differentiated tillage – 2.56, 4.55, 5.95 and 6.79 t/ha; disking tillage – 1.99, 3.99, 5.46 and 6.26 t/ha at zero, first, second and third fertilization levels, respectively.

Thus, both on unfertilized and fertilized plots of moldboard and disking tillage, this indicator is significantly reduced, while in differentiated tillage it increases slightly.

According to the yield of marketable and non-marketable products of agrophytocenoses, the mouldboard and differentiated tillage in crop rotation are equivalent and the chisel disc and disking tillage are significantly inferior to the control.

Under the zero, first, second and third fertilisation systems, grain yields were 2.29, 3.96, 5.08 and 5.59 t/ha in the first tillage variant, 1.92, 3.51, 4.62 and 5.05 in the second, 2.31, 3.96, 5.10 and 5.61 in the third, 1.73, 3.41, 4.51 and 5.03 t in the fourth, and feed units of marketable and non- marketable products were 3.60, 6.29, 8.17 and 9.05 t/ha; 3.08, 5.67, 7.47 and 8.27 t/ha; 3.60, 6.33, 8.22 and 9.13 t/ha and 2.71, 5.52, 7.41 and 8.30 t/ha respectively.

For all tillage options, the lowest cost per ton of feed units and the highest net profit and profitability were obtained by applying a crop rotation of 6 tons of manure + $N_{98}P_{66}K_{92}$per hectare of arable land.

For mouldboard, these indicators were 3.26 thousand UAH/t, 10.40 thousand UAH/ha and 43.6%, for chisel disc – 3.63; 8.30 and 34.6, for differentiated – 3.17; 11.78 and 51.0, for disking – 3.40 thousand UAH/t; 8.15 thousand UAH/ha and 36.8%, respectively (Table 5).

The energy yield and energy efficiency coefficients of marketable and non-marketable products were 116.0 and 244.4 GJ/ha; 2.2 and 4.6 in the first tillage variant, 87.5 and 186.0; 2.0 and 4.3 in the second, 117.2 and 244.8; 2.3 and 4.8 in the third, and 84.6 and 180.2 GJ/ha; 2.0 and 4.2 in the fourth, respectively.

The highest energy efficiency coefficients were recorded for the second fertilization system, which involves the application of 6 tons of manure + $N_{98}P_{66}K_{92}$ per hectare of crop rotation.

Further increase in fertilizer is inefficient, as it increases the energy yield with the crop, but reduces the level of profitability and energy efficiency.

CONCLUSIONS

According to the greening index, the zero level of fertilization in crop rotation corresponds to biological agriculture, the first level to ecological agriculture, and the second and third levels to its biologisation. According to the ecological classification, the third fertilisation system indicates an intensive level of greening of agricultural production, while the first and second systems indicate an increasing level.

The yield of the main crop in the rotation is significantly reduced under chisel disc and disking tillage. Under differentiated tillage, this indicator decreases slightly for peas, maize and white mustard in the link with peas, and increases slightly for winter wheat and buckwheat. The yield of white mustard in the link with buckwheat also increases under this tillage.

In terms of crop rotation productivity, the mouldboard and differentiated tillage are equivalent, while the chisel disc and disking tillage are significantly inferior to the control.

The highest indicators of economic and energy efficiency were obtained with differentiated tillage with the application of 6 tons of manure + $N_{98}P_{66}K_{92}$ per hectare of crop rotation.

It is recommended that in a five-field grain crop rotation, ploughing (mouldboard) should be carried out only for corn (to a depth of 25-27 cm), differentiated tillage for peas (to a depth of 18-20 cm), and disking tillage should be used for other crops (to a depth of 6-12 cm) with the application of 6 tons of manure + $N_{98}P_{66}K_{92}$per hectare of arable land and the use of non-marketable products as organic fertilizer.

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