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PRODUCTIVITY OF GRAIN EAR CROPS AND POST-HARVEST WHITE MUSTARD ON GREEN FERTILIZER DEPENDING ON THE SYSTEMS OF SOIL BASIC TILLAGE IN THE FOREST STEPPE OF UKRAINE

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Abstract

Five-year (2017-2021) studies on a typical deep low-humus black soil at the experimental field of Bila Tserkva National Agrarian University found that the yield of winter wheat and spring barley was almost at the same level with mouldboard and differentiated tillage in the five-field crop rotation. The research was conducted by the method of field stationary experiment. All crop rotation fields are fully deployed in space and time. The area of sown plots was 171 m^2, accounting area – 112 m^2. Repetition – three times, placement of repetitions and plots was consistent, systematic. In the tillering phase of winter wheat and spring barley, mouldboard-mouldboardless tillage had the advantage of arable layer moistening. When sowing white mustard, the most moisturized soil layers were under differentiated tillage, the least moisturized – under mouldboardless tillage. The dry mass of root residues of winter wheat was the highest under mouldboard, spring barley – under mouldboard-mouldboardless tillage, and white mustard was almost the same under these cultivation options. Grain yield was at the same level under mouldboard and differentiated tillage. The green mass of white mustard applied in the soil was significantly more under the differentiated tillage and predecessor of spring barley. The highest indicators of economic and energy efficiency were obtained by applying 12 tons of manure + $N_{95}P_{82}K_{72}$ per hectare of arable crop rotation land (including per winter wheat $N_{125}P_{90}K_{70}$, spring barley $N_{60}P_{50}K_{50}$, white mustard $N_{15}P_{15}K_{15}$) and carrying mouldboard-mouldboardless tillage in crop rotation, which involves deep cultivation of 25-27 cm in only one field, and the rest of the fields – mouldboardless and disk shallow tillage.

Key words: *tillage, fertilizer, soil, crop rotation, moisture, root residues, yield, productivity, efficiency*

INTRODUCTION

According to the importance of the problems of domestic farming, dehumidification of soils takes the second place (first place – erosion and deflation) [13, 19]. The content and composition of humus is an integral indicator of soil fertility. Every year, each hectare of arable land of Ukrainian black soil loses more than 1 ton of humus, which is equal to 18-20 tons of semi-rotted cattle manure on straw litter, the rate of application of which in the country today is only half a ton per hectare [2, 34].

The large number of agricultural technological works that are executed under the conventional technologies can reduce the natural soil fertility by modifying the soil agrochemical indicators [8, 10].

A convincing factor in the dominant value of humus in soil fertility, in particular, is the fact that it contains 95-98% of soil nitrogen, 80 – sulfur and 60 – phosphorus, and 50-60% of alienated nitrogen by crops from soils of humus origin, i.e. it is its mineral forms created by the mineralization of humus [18, 20].

An alternative to manure in domestic arable farming should be primarily scientifically substantiated use of non-marketable agricultural products and green manures [17, 22]. After all, according to scientists, one ton of straw in terms of organic matter content is equivalent to 3.5-4.0 tons of manure, and applied in the soil 4.0-5.0 tons of straw provide the formation of 2.6 tons of humus [23, 30].

From the green fertilizers in Ukraine today the most common crops are the cabbage family, especially in post-harvest sowing [25, 29]. Green manures of post-harvest sowing period are placed in crop rotations of the Forest-Steppe of Ukraine, as a rule, after cereals ear crops, first of all after winter wheat and spring barley. The system of basic tillage for cereals ear and post-harvest cabbage crops today needs to be revised and detailed depending on the type, subtype, structure of sown areas, and number of fields, specialization and crop rotation fertilization system.

Today there are some recommendations of scientists on tillage for basic and post-harvest crops, but they are quite general, sometimes even contradictory, often do not take into account weather and climatic conditions, soil differences, predecessors, etc. [21, 26, 29].

In the experiments of the National University of Life and Environmental Sciences of Ukraine, the use of green mass of oilseed radish for fertilizer provided a decrease in the density of typical black soil for both plowing and deep mouldboardless tillage on 0.05 g/cm^3 and increased productive moisture reserves in the arable soil on 2.5 mm, and the yield of potato tubers, respectively, on 5.2 and 7.0 tons [12].

Systematic application of only mineral fertilizers without replenishment of the soil with organic matter leads to the dominance of mineralization of soil organic matter, in particular, and humus over synthesis (humification) [33].

On the podzolic black soil of Khmelnytsky research station and typical black soil in stationary experiment of the National University of Life and Environmental Sciences of Ukraine (Kyiv region, Fastiv district) in short- course crop rotations, the highest reserves of soil humus were recorded with combined use of manure, straw, green and half the rate of mineral fertilizers and mouldboardless tillage with periodic mouldboard plowing under sugar beets. In the plowed areas of podzolic black soil hydrolytic acidity had reached a critical value (4.24-4.38 mg.eq./100 g of soil) with the combined use of straw, green manure and high rates of mineral fertilizers. In unfertilized variants, a decrease in the hydrolytic acidity was observed with an increase in the degree of tillage minimization of typical and podzolic black soil [1].

In the southern black soil the highest productivity of green manure crops was provided by mouldboardless tillage for all crops of the five-field crop rotation [32].

Sweep plowing of leached low-humus medium loam black soil in combination with the applying of optimized rates of mineral fertilizers on the background of the effect and after-effect of bare and siderate fallow land provided an increase and improvement in the structure of spring wheat yield [15].

With insufficient soil moisture in the steppe zone, plowing 20-25 cm under soybeans has advantages over sweep plowing to the same depth and shallow hoeing of 10-12 cm of ordinary black soil [9].

In the five-field crop rotation of the Left-Bank Forest-Steppe of Ukraine with peas in unfertilized plots, the average yield of winter wheat under plowing and surface cultivation for 42 years of research was on 0.29 and 0.05 t/ha, respectively, lower than under deep mouldboardless hoeing, where this indicator was 3.56 t/ha. With the application of $N_{66}P_{62}K_{82}$, the yield of winter wheat in two crop rotations was also the highest under mouldboardless tillage [5].

The maximum moisture accumulation efficiency of typical deep medium loam black soil was recorded under shallow mouldboardless tillage, carried out simultaneously with slitting, which provided an increase in available soil moisture reserves in the arable layer on 6-18% compared to mouldboard tillage. The scientist recommends the use of mouldboard-mouldboardless main tillage in the ten-field crop rotation, during which deep plowing is carried out under sugar beets and sunflowers, shallow mouldboardless tillage – under winter wheat after corn for silage and soybeans, and different depth chiseling – under other crops [31].

Kirovohrad Institute of Agricultural Production recommends farms in the northern part of the Steppe of Ukraine under winter wheat after fallow land to use mouldboardless tillage, after corn for silage – shallow (10-12 cm) disk tillage, or "zero", provided plowing under the predecessor. Under spring barley, it is proposed to cultivate ordinary medium loam black soil with a flat cut to a depth of 20-22 cm, but under the condition of deep (28-30 cm) plowing under the predecessor. In crop rotation, mouldboard-mouldboardless tillage is recommended, in which plowing for row crops alternates with "zero" tillage for agrophytocenoses with usual row sowing method [4].

In the experimental field of Uman National University of Horticulture, high efficiency in short-course crop rotation was provided by fallow plowing under soybean to a depth of 15-17 cm, spring wheat, spring barley, spring rape and oil flax – 25-27 cm [11].

In the five-field crop rotations (fruit-changing and grain plowing) of the Right-Bank Forest-Steppe of Ukraine, scientists recommend deep (30-32 and 25-27 cm, respectively) plowing in only one field under row crop (fodder beets and corn, respectively), and in the rest of the fields – shallow (10-12 cm) tillage of typical deep black soil [16].

According to the results obtained Burcea M. [3] soil works methods have little influence on the humus content, its modification being insignificant and keeping within medium range limits. The work of the soil with the disc harrow determines the highest accumulation of humus, at a depth of 10-20 cm, with average values of 3.50%. The highest humus content is found in the 0-10 cm layer due to an accumulation of organic matter not introduced on the soil depth.

In the conditions stationary experiment of the Institute of Irrigated Agriculture of NAAS of Ukraine the most favorable agrophysical properties and water regime of the dark-chestnut soil for the cultivation of row crops is created under differentiated system of basic tillage with application of $N_{120}P_{60}$ + by-products per the hectare of the crop rotation area. The mentioned cultivation technology guarantees obtaining the best profitability level of 110.1% in comparison to 38.9% on the control [14].

In the South of Romania the associated influence of the soil tillage, plant density and hybrid used on the production of maize determined the highest yields by performing the combinator on the soil tillage, as basic tillage, using a density of 55,000 plants/ha and using hybrid PR36V52. Replacement the combinator tillage with plowing or direct seeding determined to obtain lower production up to 2,000 kg/ha regardless of the hybrid used [28]. Similar results were obtained in Ukraine with corn and sweet sorghum [6, 7].

The purpose of the study is to identify the most optimal combination of systems of basic tillage and crop rotation fertilizer, which ensures the productivity of winter wheat and spring barley at the level of 12 and 9 t/ha of dry matter, 9 and 8 t/ha of feed units, 0.55 and 0, 40 t/ha of digestible protein, and white mustard – 20-21 t/ha of green mass with high economic and energy efficiency.

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 2017-2021 in a stationary field crop rotation, where four systems of basic tillage (Table 1) and four fertilizer systems were studied (Table 2).

In addition to the by-products of crop rotation and green mass of post-harvest white mustard, semi-rotted cattle manure, ammonium nitrate, simple granular superphosphate and potassium salt were used as fertilizers.

Soil moisture was determined by weight method [35], dry mass of root residues – by the method of Stankov [27].

Crop rotation fields were fully deployed in space and time. 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 of the elementary plot was 171 m^2 (9 x 19 m), and the accounting area was 112 m^2 (7 x 16 m). The area under the experiment was 3.7 ha.

Table 1. Systems of basic tillage in crop rotation

№ field	Crop	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 (г)	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.)
5	Maize	25-27 (p.)	25-27 (d.t.)	25-27 (d.t.)	10-12 (d.h.)

**Note*: *p. – plowing, d.h. – disc harrow, d.t. – deep tiller.*
Source: Authors' own results.

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

№ field	Crop rotation crops	Fertilizer level	Manure, t/ha	Mineral fertilizers, kg/ha a.s.														
				total			basic fertilizer			under presowing cultivation			row fertilizer			feeding		
				N	P	K	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	Sunflower	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

In the upper (0-10 cm) layer of soil on the date of sowing of winter wheat at zero, first, second and third levels of fertilizer available moisture was less, respectively, on 0.8, 1.0, 1.2 and 1.3 mm under mouldboardless tillage, 0.3, 0.5, 0.6 and 0.8 – differentiated, 1.1, 1.3, 1.4 and 1.5 mm – under shallow tillage, compared with control, with SD_{05} = 1.0 mm. In the arable (0-30 cm) layer, this indicator was significantly lower under constant chisel and shallow than mouldboard tillage in crop rotation. Under mouldboard-mouldboardless and mouldboard tillage, the difference was 1.1-1.8 mm in favor of the latter, but it was insignificant.

In a meter layer of soil, the reserves of available moisture were on 5.8-9.7 mm lower under mouldboardless and disk than mouldboard tillage (SD_{05} = 5.3 mm), and with increasing rates of fertilizer, this difference increased. Thus, for chisel tillage on unfertilized plots, it was 6.1 mm, and on fertilized with $N_{150}P_{110}K_{80}$ – 9.7 mm in favor of the control (Table 3).

Table 3. Change in the available soil moisture reserves under cereals ear crops depending on the system of tillage and fertilization of typical black soil, mm

The main tillage in crop rotation	Fertilizer levels in crop rotation	Sowing of cereals						Tillering of cereals					
		winter wheat			spring barley			winter wheat			spring barley		
		layer of soil, cm											
		0-10	0-30	0-10	0-30	0-10	0-30	0-10	0-30	0-10	0-30	0-10	0-30
mouldboard (control)	0	9.3	32.5	108.1	19.3	49.6	116.4	14.6	39.4	121.3	12.3	31.1	114.8
	1	8.8	31.1	105.8	18.3	47.9	112.7	13.2	37.0	110.4	11.4	29.0	107.5
	2	8.2	30.0	102.7	16.8	45.8	108.9	12.8	35.5	103.6	10.1	27.4	102.9
	3	7.8	28.7	98.6	16.4	43.3	105.6	12.5	33.6	95.8	9.5	25.9	100.4
mouldboardless (chisel)	0	8.5	29.8	102.0	17.9	46.2	108.0	13.3	36.7	117.2	11.4	28.3	109.2
	1	7.8	28.2	98.4	16.5	43.4	102.3	11.8	34.2	106.7	10.6	25.8	101.1
	2	7.0	26.8	93.9	14.5	40.7	96.4	11.3	32.5	99.8	9.1	24.0	96.1
	3	6.5	25.1	88.9	13.9	37.6	92.2	11.2	30.7	91.7	8.8	22.4	93.3
mouldboard & mouldboardless (differentiated)	0	9.0	31.4	111.8	18.2	47.5	118.7	13.8	40.7	120.2	13.5	31.6	117.1
	1	8.3	29.7	108.6	16.8	45.3	116.1	12.3	38.6	109.6	12.8	29.7	110.6
	2	7.6	28.4	104.8	15.0	42.9	113.1	12.1	37.3	102.2	11.7	28.3	106.2
	3	7.0	26.9	100.2	14.3	40.2	110.6	11.6	35.1	94.6	11.0	26.9	104.4
disking (continuous shallow)	0	8.2	30.4	102.3	18.0	45.4	109.2	13.0	35.6	115.5	10.8	28.5	110.0
	1	7.5	28.6	99.3	16.7	43.1	103.9	11.6	33.4	104.9	10.0	26.0	102.2
	2	6.8	27.3	95.0	15.0	40.3	99.3	11.0	31.8	98.5	8.9	24.6	98.4
	3	6.0	25.8	89.7	14.0	37.3	94.8	10.7	30.1	91.0	8.3	22.7	94.9
SD_{05}		1,0	2.0	5.3	1.1	3.3	6.8	1.1	2.3	4.7	1.2	2.6	4.5

Source: Authors' own results.

On unfertilized variants, fertilized with $N_{100}P_{70}K_{50}$, $N_{125}P_{90}K_{70}$ and $N_{150}P_{110}K_{80}$ under mouldboard-mouldboardless tillage, this indicator was on 3.7, 2.8, 2.1 and 1.6 mm higher than in the control, but this difference was insignificant.

In the tillering phase of winter wheat available moisture in the upper soil layer was on 0.7-0.9 mm less under differentiated than under mouldboard tillage (SD_{05} = 1.1 mm). Under chisel and disk tillage this indicator was essentially lower (on 1.3-1.8 mm), than in control. In the arable layer of typical black soil available moisture under mouldboard-mouldboardless tillage was on 1.3-1.8 mm more, and under mouldboardless and shallow, respectively, on 2.7-3.0 and 3.5-3.8 mm less than under mouldboard (SD_{05} = 2.3 mm). The most moist meter layer of soil was in the control, where this indicator was on 0.8-1.4, 3.7-4.1 and 4.8-5.8 mm higher than, respectively, under mouldboard-mouldboardless, chisel and disk tillage in crop rotation (SD_{05} = 4.7 mm).

In the experiment of the National University of Life and Environmental Sciences of Ukraine, the content of available moisture in a meter layer of typical deep medium-loam black soil at the beginning of winter wheat vegetation was also higher than under mouldboard-mouldboardless tillage in ten-field crop rotation than in the control [31].

In the right-bank steppe of Ukraine only in dry years mouldboard-mouldboardless tillage of ordinary medium humus heavy loam black soil in crop rotation reduced the reserves of available moisture of one and a half meter layer of soil due to increased density of its structure, compared with different depth plowing [4].

On the date of sowing of spring barley available moisture in the upper layer of soil on unfertilized plots fertilized with $N_{50}P_{40}K_{40}$, $N_{60}P_{50}K_{50}$ and $N_{70}P_{60}K_{60}$ was, respectively, less on 1.4, 1.8, 2.3 and 2.5 mm under mouldboardless, 1.1, 1.5, 1.8 and 2.1 mm – differentiated, 1.3, 1.6, 1.8 and 2.4 mm under constant shallow tillage than in control. In the arable layer of soil, this indicator under chisel and disk tillage was, respectively, lower on 3.4-5.7 and 4.2-6.0 mm, and under mouldboard-mouldboardless – on 2.1-3.1 mm than in control with SD_{05} = 3.3 mm. At the same time, there was an increase in the difference of this indicator between the options of tillage with increasing levels of fertilizers. Thus, under mouldboardless, differentiated and systematic shallow tillage in crop rotation, it was, respectively, 3.4, 2.1 and 4.2 mm on unfertilized and 5.7, 2.9 and 6.0 mm on fertilized plots with the highest rate of fertilizers in favor of the control.

In the meter layer of soil, available moisture was on 2.3-5.0 mm more under mouldboard-mouldboardless tillage than under mouldboard tillage, but this difference did not reach SD_{05}, which was 6.8 mm. For chisel and disk tillage, this indicator was lower on 8.4 and 7.2 mm, respectively, on unfertilized plots, 10.4 and 8.8 mm – fertilized with $N_{50}P_{40}K_{40}$, 12.5 and 9.6 mm – $N_{60}P_{50}K_{50}$, 13.4 and 10.8 mm – $N_{70}P_{60}K_{60}$, than in the control.

In the tillering phase of spring barley, the available moisture in the upper layer of the soil was slightly higher (0.7-1.0 mm) under mouldboard than mouldboardless tillage. With differentiated tillage, this indicator was significantly higher (on 1.2-1.5 mm), and with constant shallow – significantly lower (on 1.2-1.5) than in the control.

In the arable layer of the soil, available moisture under chisel and constant shallow tillage was on 2.6-3.5 mm less, and under mouldboard-mouldboardless – on 0.5-1.0 mm more than in the control with SD_{05} = 2.6 mm. A similar pattern was observed in the meter layer, where the average value of this indicator under mouldboard, mouldboardless, differentiated and disk tillage was 106.4, 99.9, 109.6 and 101.4 mm, respectively. Thus, the reserves of available water in a meter layer of soil under chisel and systematic shallow tillage was, respectively, lower on 6.1 and 4.7%, and under mouldboard-mouldboardless – on 3.0% higher than in the control (Table 4).

The same pattern was observed in the research field of Kharkiv National Agrarian University in the root layer of typical deep low humus black soil, where mouldboardless tillage reduced soil moisture on 6 mm, compared with the control. According to the scientist, systematic mouldboardless tillage worsens the conditions of accumulation of soil moisture in the root layer of typical black soil, regardless of the depth of tillage [24].

In the experiments of the Institute of Agriculture of the steppe zone of NAAS of Ukraine on ordinary hard loam black soil, the advantage of mouldboardless tillage in field short-course crop rotations in terms of available soil moisture content was observed under the lack of normative amount of precipitation during December-February [20].

On the date of sowing of white mustard after winter wheat, available moisture in the upper layer of the soil under mouldboardless and disk tillage was, respectively, less on 1.2-1.6 and 0.8-1.1 mm, and under differentiated – on 1.3-1.8 mm more than in the control with SD_{05} = 1.2 mm. A similar pattern was recorded in the arable layer of soil; however, the magnitude of the increase in this indicator under mouldboard-mouldboardless tillage did not reach SD_{05} and was in the range of 1.4-2.3 mm. For chisel and systematic shallow tillage, this indicator was on 9.8 and 10.8% lower, respectively, than in the control.

Table 4. Change in the available soil moisture reserves under white mustard depending on predecessors, system of tillage and fertilization of typical black soil, mm

The main tillage in crop rotation	Fertilizer levels in crop rotation	Sowing						Mowing					
		Predecessors											
		winter wheat			spring barley			winter wheat			spring barley		
		layer of soil, cm											
		0-10	0-30	0-100	0-10	0-30	0-100	0-10	0-30	0-100	0-10	0-30	0-100
mouldboard (control)	0	11.7	42.2	94.7	10.2	38.6	108.3	6.0	20.1	72.3	5.8	18.4	66.8
	1	11.1	41.4	90.1	9.6	37.4	106.1	5.7	17.6	68.0	5.3	17.3	65.1
	2	10.7	39.5	87.3	9.3	36.9	104.6	5.4	15.7	64.2	5.0	16.0	64.3
	3	9.6	38.3	85.8	9.0	36.4	103.0	5.1	13.6	61.9	4.6	14.9	63.0
mouldboardless (chisel)	0	10.5	39.1	86.9	11.1	35.9	99.7	7.1	23.5	78.1	7.0	21.0	72.2
	1	9.7	37.5	81.6	10.6	34.4	97.0	6.7	20.7	73.2	6.4	19.5	70.3
	2	9.2	35.4	78.6	10.3	33.7	94.5	6.3	18.6	69.1	6.0	17.8	68.8
	3	8.0	33.5	76.7	10.1	33.0	92.3	5.9	16.2	66.6	5.5	16.6	67.2
mouldboard & mouldboardless (differentiated)	0	13.0	43.6	97.9	11.7	41.2	115.5	5.3	17.0	68.6	4.6	15.6	62.3
	1	12.6	43.1	93.7	11.2	40.4	114.2	4.9	14.8	64.5	4.2	14.8	61.0
	2	12.3	41.5	91.2	11.0	40.1	113.8	4.5	13.1	60.8	4.0	13.9	60.4
	3	11.4	40.6	89.9	10.8	39.7	113.4	4.2	11.2	58.7	3.6	12.9	59.2
disking (continuous shallow)	0	10.9	38.6	89.1	10.9	35.6	100.8	7.0	23.2	77.8	6.9	20.9	71.1
	1	10.2	37.3	83.7	10.4	34.2	98.0	6.7	20.4	73.1	6.4	19.5	69.3
	2	9.7	34.9	80.5	10.2	33.5	95.3	6.3	18.2	69.1	6.2	18.0	67.6
	3	8.5	33.1	78.5	10.0	32.8	93.2	5.9	15.8	66.8	5.9	16.7	66.9
SD_{05}		1.2	2.6	5.1	1.3	2.4	6.2	0.8	2.2	3.4	0.9	1.8	3.1

Source: Authors' own results.

The most moist meter layer of typical black soil was under differentiated tillage, although the increase in available moisture in it (which was 3.2-4.1 mm) compared with the control was insignificant. Reserves of available water in this layer of soil was higher on 9.6 and 7.3%, respectively, under mouldboardless and disk than mouldboard tillage in crop rotation.

On the date of sowing of green manure after spring barley, available water in the upper layer of soil was on 0.9-1.1 and 1.3-1.8 mm more, respectively, under chisel and mouldboard-mouldboardless, than mouldboard tillage (SD_{05} = 1.3 mm). The magnitude of the increase in this indicator (on 0.8-1.1 mm) with systematic shallow tillage, compared with the control, was insignificant.

In the arable and meter layers of typical black soil, reserves of available moisture was significantly higher under differentiated and significantly lower under mouldboardless and disk, than mouldboard tillage in crop rotation. The reduction of this indicator in the these layers of soil was respectively 2.7-3.4 and 8.6-10.1 mm under chisel, 3.0-3.6 and 7.5-9.8 mm under constant shallow tillage, and an increase on 2.6-3.3 and 7.2-10.4 mm under mouldboard mouldboardless tillage, compared with the control, with SD_{05} 2.4 and 6.2 mm.

At the date of applying green fertilizer into the soil, the lowest reserves of available moisture in the studied soil layers were observed after both predecessors under mouldboard-mouldboardless tillage in crop rotation. The decrease in this indicator in the layers 0-10, 0-30 and 0-100 cm was 0.7-1.2, 2.0-3.1 and 3.2-4.5 respectively under differentiated tillage; an increase on 0.8-1.2, 1.7-3.4 and 3.3-5.8 mm – under mouldboardless and disk tillage, compared to the control associated with different crop productivity.

The highest grain yield of winter wheat was obtained under mouldboard tillage in crop rotation. Under chisel and systematic shallow tillage, it was significantly lower, and under mouldboard-mouldboardless – insignificantly lower than in the control. With increasing rates of fertilizer, the difference in yield between cultivation options increased. Thus, on unfertilized plots fertilized with $N_{100}P_{70}K_{50}$, $N_{125}P_{90}K_{70}$ and $N_{150}P_{110}K_{80}$, the decrease in this indicator was 0.43, 0.56; 0.63 and 0.71 t/ha respectively under mouldboardless, 0.12, 0.18, 0.23 and 0.27 t/ha

– differentiated, 0.33, 0.46, 0.56 and 0.61 t/ha – under disk tillage, compared with the control (Table 5).

Table 5. Yield and mass of root crop residues under different systems of basic tillage and fertilizer in crop rotation, t/ha

The main tillage in crop rotation	Fertilizer levels in crop rotation	Yield, t/ha				The ratio of grain to straw		Yield of green mass of white mustard, t/ha		Mass of root residues, t/ha of dry matter winter wheat			
		winter wheat		spring barley								of white mustard	
		grain	straw	grain	straw	of winter wheat	of spring barley	after winter wheat	after spring barley	of winter wheat	of spring barley	after winter wheat	after spring barley
mouldboard (control)	0	2.73	3.30	2.37	2.56	1.21	1.08	9.86	8.83	2.04	1.72	1.81	1.62
	1	4.78	6.12	3.74	4.19	1.28	1.12	17.75	14.10	2.88	2.19	3.03	2.40
	2	6.35	8.51	4.78	5.64	1.34	1.18	21.88	18.26	4.17	2.87	3.75	3.14
	3	7.80	10.76	5.67	6.92	1.38	1.22	23.79	21.09	5.19	3.42	4.06	3.63
mouldboardless (chisel)	0	2.30	2.85	2.05	2.28	1.24	1.11	8.63	7.50	1.77	1.54	1.65	1.38
	1	4.22	5.49	3.32	3.82	1.30	1.15	16.30	12.51	2.59	1.99	2.89	2.12
	2	5.72	7.78	4.29	5.19	1.36	1.21	20.21	16.47	3.81	2.63	3.60	2.82
	3	7.09	10.00	5.11	6.44	1.41	1.26	21.95	19.13	4.77	3.13	3.89	3.28
mouldboard & mouldboardless (differentiated)	0	2.61	3.11	2.53	2.68	1.19	1.06	9.48	10.28	1.97	1.86	1.78	1.89
	1	4.60	5.75	3.87	4.30	1.25	1.11	17.26	15.44	2.79	2.29	3.00	2.61
	2	6.12	8.02	4.86	5.59	1.31	1.15	21.23	19.53	4.04	2.94	3.71	3.33
	3	7.53	10.17	5.73	6.88	1.35	1.20	22.98	22.28	5.03	3.48	4.02	3.79
disking (continuous shallow)	0	2.40	3.02	2.13	2.43	1.26	1.14	8.31	7.19	1.84	1.59	1.52	1.32
	1	4.32	5.75	3.41	3.99	1.33	1.17	15.96	12.22	2.64	2.05	2.69	2.04
	2	5.79	7.99	4.40	5.46	1.38	1.24	19.91	16.19	3.84	2.69	3.38	2.74
	3	7.19	10.35	5.25	6.72	1.44	1.28	21.66	18.89	4.83	3.22	3.69	3.22
SD_{05}		0.33	0.41	0.22	0.28			1.07	1.14	0.19	0.13	0.14	0.18

Source: Authors' own results.

Table 6. The output of by-products of cereals ear crops under different systems of basic tillage and fertilizer in crop rotation, t/ha

The main tillage in crop rotation	Fertilizer levels in crop rotation	Natural value		Dry matter		Fodder units		Digestible protein	
		winter wheat	spring barley	winter wheat	spring barley	winter wheat	spring barley	winter wheat	spring barley
mouldboard (control)	0	3.28	2.52	2.80	2.21	0.92	0.93	0.0131	0.0302
	1	5.80	4.06	4.95	3.56	1.62	1.50	0.0232	0.0487
	2	7.87	5.28	6.71	4.64	2.20	1.95	0.0315	0.0634
	3	9.83	6.40	8.38	5.62	2.75	2.37	0.0393	0.0768
mouldboardless (chisel)	0	2.89	2.33	2.47	2.05	0.81	0.86	0.0116	0.0280
	1	5.38	3.87	4.59	3.40	1.51	1.43	0.0215	0.0464
	2	7.37	5.06	6.29	4.44	2.06	1.87	0.0295	0.0607
	3	9.29	6.10	7.92	5.36	2.60	2.26	0.0372	0.0732
mouldboard & mouldboardless (differential)	0	3.17	2.75	2.70	2.41	0.89	1.02	0.0127	0.0330
	1	5.70	4.28	4.86	3.76	1.60	1.58	0.0228	0.0514
	2	7.71	5.47	6.58	4.80	2.16	2.02	0.0308	0.0656
	3	9.62	6.57	8.21	5.77	2.69	2.43	0.0385	0.0788
disking (continuous shallow)	0	2.96	2.39	2.52	2.10	0.83	0.88	0.0118	0.0287
	1	5.41	3.93	4.61	3.45	1.51	1.45	0.0216	0.0472
	2	7.37	5.13	6.29	4.50	2.06	1.90	0.0295	0.0616
	3	9.31	6.20	7.94	5.44	2.61	2.29	0.0372	0.0744
SD_{05}		0,31	0.28	0.27	0.25	0.09	0.10		

Source: Authors' own results.

The grain yield of spring barley was almost at the same level under mouldboard-mouldboardless and mouldboard tillage, and under chisel and constant shallow – significantly lower. Under mouldboardless and disk tillage, this indicator was lower on 10.9 and 8.2%, respectively, and under differentiated – higher on 2.7% than in the control.

The ratio of basic to by-products under mouldboard, chisel, mouldboard-mouldboardless and systematic shallow tillage in crop rotation was 1.30, 1.33, 1.28 and 1.35 respectively in winter wheat and 1.15, 1.18, 1.13 and 1.21 – in spring barley. Thus, this indicator was highest under disk and mouldboardless, the lowest – under differentiated tillage. On all variants of tillage with increase in norms of the applied fertilizers it grew.

The yield of winter wheat straw was significantly lower under chisel and disk than mouldboard tillage. Under mouldboard-mouldboardless tillage this indicator for winter wheat was lower than in the control, but insignificant. With differentiated tillage, the yield of straw of spring barley was on 0.17-0.23 t/ha higher, and with constant shallow tillage on 0.13-0.20 t/ha lower than in the control (SD_{05} = 0.28 t/ha) (Table 6).

Burcea M. [3] noted that total nitrogen content in the soil was lower in the variants with plowing and disk works, and the variant worked with the chisel determined the best mineralization of the nitrogen. The difference between the variants in terms of total nitrogen content is generated by the distribution of organic matter on the soil profile and the microbiological activity in the soil and decreases on the depth of the arable layer.

The yield of green mass of white mustard under sowing it after winter wheat was the highest under mouldboard tillage in crop rotation, and under chisel, mouldboard-mouldboardless and disk tillage, it decreased on 1.23-1.84, 0.38-0.81 and 1.55-2.13 t/ha, respectively, with SD_{05} = 1.07 t/ha.

As the level of applied fertilizers increased, this difference between cultivation options increased.

Under sowing of white mustard after spring barley, a significant increase in green mass (1.19-1.45 t/ha) was recorded under differentiated tillage compared to the control. Under mouldboardless and systematic shallow tillage, green mass was received less on 1.33-1.96 and 1.64-2.20 t/ha respectively than in the control with SD_{05} = 1.14 t/ha.

The mass of root residues of winter wheat in the arable layer of the soil was the highest under mouldboard tillage, and under chisel, mouldboard-mouldboardless and disk it was on 0.27-0.42, 0.07-0.16 and 0.20-0.36 t/ha less, respectively (SD_{05} = 0.19 t/ha).

The root residues of spring barley was slightly more (on unfertilized plots significantly) under mouldboard-mouldboardless than mouldboard tillage. This indicator was significantly reduced (on 0.13-0.20 t/ha) on the variants under mouldboardless and constant shallow tillage, compared with the control.

As the level of fertilizer increased, both the yield and the mass of root residues of the studied crops increased. However, the latter indicator rose much more slowly than the former. Thus, under fertilization of winter wheat with $N_{100}P_{70}K_{50}$, $N_{125}P_{90}K_{70}$, $N_{150}P_{110}K_{80}$ the increase in grain, compared with unfertilized plots, under mouldboard tillage was 75.1, 132.6, 185.7%, root mass – 41.2, 104.4, 154.4%, mouldboardless – 83.5, 148.7, 208.3 and 46.3, 115.3, 169.5%, differentiated – 76.2, 134.5, 188.5 and 41.6, 105.1, 155.3%, disk – 80.0, 141.3, 199.6 and 43.5, 108.7, 162.5%. The lag of the growth of root mass from the yield under the application of the above fertilizer rates was, respectively, 33.9, 28.2, 31.3% under mouldboard cultivation, 37.2, 33.4, 38.8% – chisel, 34.6, 29.4, 33.2% – mouldboard-mouldboardless, 36.5, 32.6, 37.1% – under systematic shallow tillage.

In spring barley, as well as in winter wheat, increase in dry weight of roots was slower than in marketable products, on fertilized variants, compared with unfertilized, recorded under mouldboardless and disk tillage. In the fertilized plots with $N_{50}P_{40}K_{40}$, $N_{60}P_{50}K_{50}$, $N_{70}P_{60}K_{60}$, compared to the unfertilized, the increase was 57.8, 101.7, 139.2% of grain and 27.3, 66.9, 98.8% of the root mass under mouldboard tillage, 61.9, 109.3, 149.3 and 29.2, 70.8, 103.2% – mouldboardless, 53.0, 92.1, 126.5 and 23.1, 58.1, 87.1% – differentiated, 60.1, 106.6, 146.5 and 28.9, 69.2, 102.5% under disk tillage. The increase in root mass was less than the increase in grain at the above rates of fertilizers, compared with unfertilized plots, respectively, on 30.5, 34.8, 40.4% under mouldboard tillage, 32.7, 38.5, 46.1% – chisel, 29.9, 34.0, 39.4% – mouldboard-mouldboardless, 31.2, 37.4, 44.0% – under constant shallow tillage.

In white mustard on fertilized plots, compared with unfertilized, the slowdown in root growth compared to aboveground mass, was less than in winter wheat and spring barley. During the sowing of this crop after winter wheat on the variants under application of the first, second and third levels of fertilizer in crop rotation, the increase in root mass lagged behind the increase in aboveground, compared with unfertilized plots, respectively, on 10.6, 14.7 and 17.0% under mouldboard tillage, 13.7, 16.0 and 18.5% – mouldboardless, 13.6; 15.5 and 16.6% – differentiated, 15.1, 17.2 and 17.8% under disk tillage.

After spring barley for the first, second, third levels of fertilization in crop rotation, the increase in green mass of white mustard, compared with unfertilized plots, was respectively 59.7, 106.8, 138.8% and root residues – 48.1, 93.8, 124.1% under mouldboard tillage, 66.8, 109.6, 155.1 and 53.6, 104.3, 137.7% – chisel, 50.2, 90.0, 116.7 and 38.1, 76.2, 100.5% – mouldboard-mouldboardless, 70.0, 125.2, 162.7 and 54.5, 107.6, 143.9% under constant shallow tillage. The difference in the growth of aboveground and underground mass at these levels of fertilizer was 11.6, 13.0, 14.7% in the control variant, 13.2, 15.3, 17.4% – under mouldboardless tillage, 12.1, 13.8, 16.8% – differentiated, 15.5, 17.6, and 18.8% – under disk tillage.

In winter wheat and spring barley, the widest ratio of grain to dry mass of root residues was under mouldboard tillage (respectively 1.505 and 1.605), the narrowest – under chisel hoeing (1.480 and 1.565). In white mustard, these differences were less expressed.

The widest ratio of grain and green manure to dry mass of roots was recorded at the first level of fertilizer, the narrowest – on unfertilized plots. Thus, at zero, first, second and third levels of fertilizer, this indicator was, respectively, 1.315, 1.645, 1.513 and 1.495 in winter wheat, 1.353, 1.683, 1.648 and 1.643 – in spring barley, 5.443, 5.923, 5.858 and 5.848 – in white mustard (after spring barley).

The dry matter of grain and straw of winter wheat was obtained significantly less under mouldboardless and disk tillage and insignificantly – under differentiated than mouldboard tillage in crop rotation. On the unfertilized plots of the plants, fertilized with $N_{100}P_{70}K_{50}$, $N_{125}P_{90}K_{70}$ and $N_{150}P_{110}K_{80}$, the collection of feed units of grain and straw was lower, respectively, on 0.61, 0.76, 0.88 and 0.98 t/ha under chisel tillage, 0.17, 0.23, 0.31 and 0.38 – mouldboard-mouldboardless, 0.47, 0.65, 0.80 and 0.86 t/ha – under shallow tillage, compared with the control. A similar pattern was observed for the output of digestible protein. With increasing fertilizer rates, the difference in the productivity of winter wheat between tillage options increased (Table 7).

Productivity of spring barley (grain + straw) on the unfertilized variants fertilized with $N_{50}P_{40}K_{40}$, $N_{60}P_{50}K_{50}$ and $N_{70}P_{60}K_{60}$ under mouldboardless tillage was, respectively, lower on 0.47, 0.59, 0.68 and 0.79, disk – 0.35, 0.46, 0.52 and 0.59 t/ha of fodder units, and under differentiated – on 0.28, 0.24, 0.17 and 0.14 t/ha higher than in the control. Dry matter and digestible protein from the main and by-products were obtained on average, respectively, – 3.56 and 0.349 t/ha under mouldboard tillage, 3.18 and 0.315 – chisel, 3.66 and 0.359 – mouldboard-mouldboardless, 3.27 and 0.323 t/ha under shallow tillage in crop rotation.

The productivity of winter wheat (grain + straw) on unfertilized plots fertilized with $N_{100}P_{70}K_{50}$, $N_{125}P_{90}K_{70}$ and $N_{150}P_{110}K_{80}$ was respectively 4.79, 8.62, 11.61 and 14.49 t/ha of dry matter, 3.80, 6.80, 9.13 and 11.33 t/ha of feed units, 0.226, 0.403, 0.540 and 0.668 t/ha of digestible protein.

When the applying $N_{50}P_{40}K_{40}$, $N_{60}P_{50}K_{50}$ and $N_{70}P_{60}K_{60}$ under spring barley, its productivity (grain + straw) increased, respectively, on 2.48, 4.39 and 6.08 t/ha of dry matter, 2.18, 3.85 and 5.31 t/ha of feed units, 0.112, 0.197 and 0.271 t/ha of digestible protein, compared with unfertilized variants, where these indicators were, respectively, 4.15, 3.72 and 0.191 t/ha.

Table 7. Productivity of fields of cereals ear crops under various systems of the main tillage and fertilizers in crop rotation, t/ha

The main tillage in crop rotation	Fertilizer levels in crop rotation	Winter wheat				Spring barley			
		Dry matter		fodder units (grain+straw)	digestible protein (grain+straw)	Dry matter		fodder units (grain+straw)	digestible protein (grain+straw)
		grain	grain+straw			grain	grain+straw		
mouldboard (control)	0	2.35	5.15	4.11	0.245	2.04	4.25	3.85	0.198
	1	4.12	9.07	7.21	0.429	3.22	6.78	6.10	0.315
	2	5.47	12.18	9.63	0.572	4.11	8.75	7.83	0.402
	3	6.72	15.10	11.88	0.702	4.88	10.50	9.34	0.480
mouldboardless (chisel)	0	1.98	4.45	3.50	0.208	1.76	3.81	3.38	0.174
	1	3.64	8.23	6.45	0.381	2.86	6.26	5.51	0.282
	2	4.93	11.22	8.75	0.516	3.69	8.13	7.15	0.366
	3	6.11	14.03	10.90	0.640	4.39	9.75	8.55	0.436
mouldboard & mouldboardless (differentiated)	0	2.25	4.95	3.94	0.235	2.18	4.59	4.13	0.213
	1	3.97	8.83	6.98	0.414	3.33	7.09	6.34	0.326
	2	5.28	11.86	9.32	0.551	4.18	8.98	8.00	0.411
	3	6.49	14.70	11.50	0.679	4.93	10.70	9.48	0.486
disking (continuous shallow)	0	2.07	4.59	3.64	0.216	1.83	3.93	3.50	0.180
	1	3.72	8.33	6.56	0.389	2.93	6.38	5.64	0.289
	2	4.99	11.28	8.83	0.522	3.78	8.28	7.31	0.374
	3	6.20	14.14	11.02	0.649	4.52	9.96	8.75	0.447
SD_{05}		0.28	0.49	0.41	0.026	0.19	0.31	0.28	0.017

Source: Authors' own results.

The average productivity of winter wheat and spring barley according to the experimental variants was 9.88 and 7.39 t/ha of dry matter, 7.77 and 6.56 t/ha of feed units, 0.459 and 0.336 t/ha of digestible protein, respectively.

The lowest cost of one grain ton of winter wheat and spring barley (respectively, 3.89 and 3.78 thousand UAH), the highest conditionally net profit (6.36 and 4.32 thousand UAH/ha) and the level of profitability (34.9 and 32.4%) were obtained in the experiment under mouldboard-mouldboardless tillage in crop rotation and application per hectare of arable land 12 tons of manure + $N_{95}P_{82}K_{72}$, including $N_{125}P_{90}K_{70}$ under winter wheat and $N_{60}P_{50}K_{50}$ – under spring barley. In this variant, the energy output with the yield of the main production of the above-mentioned crops was 78.1 and 57.7 GJ/ha, respectively, the main and secondary – 178.1 and 120.9 GJ/ha; coefficient of energy efficiency of marketable products – 1.4 and 2.3, and marketable and non-marketable – 3.2 and 4.8.

CONCLUSIONS

On the date of sowing of winter wheat reserves of available moisture in the upper (0-10 cm) layer of soil were highest under mouldboard tillage in crop rotation, in arable (0-30 cm) and meter layers – under mouldboard-mouldboardless tillage. In the tillering phase, its upper and meter layers of soil are most moist under mouldboard tillage, and arable – under differentiated. Mouldboardless and disk tillage were significantly inferior to the control variant. On the date of sowing of spring barley, the advantage of this indicator was in the upper and arable layers of the soil under mouldboard tillage, in the meter – under differentiated.

In the tillering phase of the crop, available moisture in the studied layers of typical black soil was the most under mouldboard-mouldboardless tillage, the least – under chisel and disk.

On the date of sowing of white mustard after both predecessors, the most moist soil layers were under differentiated tillage, and at the end of the growing season the reverse pattern was observed.

The ratio of grain to straw was the widest under shallow and mouldboardless tillage, the narrowest – under mouldboard-mouldboardless.

The dry mass of root residues of winter wheat was the largest under mouldboard tillage, and spring barley – under differentiated. Significantly lower values of this indicator were under mouldboardless and disk tillage. With increasing fertilizer rates, it grew more slowly than the mass of grain or green manure.

Yield of grain crops was almost at the same level under mouldboard and mouldboard-mouldboardless tillage in crop rotation. Applied in the soil green mass of white mustard after winter wheat was significantly more under mouldboard tillage, and after spring barley – significantly more under differentiated tillage. Under systematic mouldboardless and shallow tillage, the productivity of the main and post-harvest crops was significantly reduced.

The highest indicators of economic efficiency of growing cereals with post-harvest white mustard for green manure were obtained by applying 12 tons of manure per hectare of crop rotation + $N_{95}P_{82}K_{72}$ (including $N_{125}P_{90}K_{70}$ under winter wheat, $N_{60}P_{50}K_{50}$ under spring barley, $N_{15}P_{15}K_{15}$ under white mustard) and carrying out differentiated main tillage in crop rotation, which involves deep (25-27 cm) cultivation in only one field, and in the rest of the fields – mouldboardless and disk shallow tillage.

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