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ORIGINAL ARTICLE

Nitrogen balance in short crop rotations under various systems for restoring sod-podzolic soil fertility

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The influence of traditional organic-mineral, mineral, alternative (ecological) fertilizer systems on the nitrogen regime of the soil and nitrogen balance in the system "fertilizer-plant"in the conditions of Left Bank Chernihiv Polissya of Ukraine is studied.
The fertilizer systems, influenced by grain and grain-potato short crop rotations on the soil and nitrogen balance, are presented. The intensity of nitrogen balance in traditional, mineral, organic, and alternative fertilizer systems in grain and grain-potato short crop rotations has been established. Nitrogen input into the soil with roots, post-harvest residues, by-products, and green manure was determined. The influence of crop set in crop rotations on the nitrogen regime of sod-podzolic sandy soil is determined.
Keywords: short crop rotations, fertilization systems, sod-podzolic sandy loam soil, soil nitrogen regime, nitrogen balance.

Introduction

The balance of nutrients in agriculture allows interfering with the cycle of nutrients both by introducing the necessary amount of nutrients and by creating an optimal set and ratio of crops in the structure of sown areas (Peterburgsky, 1979; Tsvei, 2000; Pryanishnikov, 1965; Tarariko, 2005; Zakharchenko et al., 1974; Karbivska et al., 2020, 2020a; Karpenko et al., 2020a; Scalise et al., 2015).
The study of nutrient balance in agriculture is one of the main components in regulating the biogeochemical transfer between humans and nature. This problem is of primary importance in connection with the need to develop and implement measures to protect nature and improve the environmental situation to ensure the sustainable development of society (Peterburgsky, 1979; Tsvei, 2000; Pryanishnikov, 1965; Tarariko, 2005; Manko et al., 2019; Iannetta et al., 2016; Litvinov et al., 2020).
The real challenge is the fragmentation of agricultural land massifs and the emergence of small agricultural enterprises that use short crop rotations in agricultural production. In many farms with a shortage of organic fertilizers (manure), a mineral fertilizer system is used. Simultaneously, due to environmental problems, one of the directions of sustainable development in the agricultural sector is the implementation of organic farming (Karpenko et al., 2019, 2020; Tonkha et al., 2021; Litvinov et al., 2019; Tilman et al., 2011). These circumstances require improving the effectiveness of alternative fertilizer systems, in which organic fertilizer is, used as by-products of crops in short crop rotations.
The article aimed to determine the effectiveness of various fertilizer systems in short crop rotations based on the fertilizer - plant system's balance method.

Materials and methods

The research was conducted in a long-term stationary experiment of the Scientific Support Department of Agro-Industrial Production of the Institute of Agricultural Microbiology and Agro-Industrial Production of NAAS (Ukraine). The experiment is considered two short-term four-field crop rotations: crop rotation I - grain crop rotation (Clover - Winter wheat - Corn - Spring wheat) and crop rotation II - grain-potato crop rotation (Narrow-leaf lupine - Winter rye - Potatoes - Hulless oat).
In 2006-2018, the traditional (organic and mineral) fertilizer system provided the input of 10 t/ha of animal manure + N68P53K60 kg/ha; for mineral fertilizer system - N68P53K60 kg/ha; for organic I fertilizer system - 10 t/ha of animal manure; for organic II fertilizer system - 20 t/ha of animal manure; variant of an ecological (alternative) fertilizer system, introduced in 2006 included narrow-leaf lupin as green manure + by-products + N68P53K60 kg/ha of crop rotation.
Using regression equations (Zakharchenko et al., 1974; Levin, 1977; Balyuk et al., 2011, Notaris et al., 2018; Karbivska et al., 2019), the intake of organic matter into the soil and the content of nutrients in the leadingproducts and by-products of crop rotations were calculated. Determination of nitrogen in the soil was carried out according to generally accepted methods. For an objective assessment, we used the results of yield data from the study period 2006-2018, from the moment of transition to short crop rotations and the introduction of alternative fertilizer systems.

Results and discussion

Plant remains and roots of legumes are the important source of organic matter replenishment and nitrogen reserves in the soil. Soil replenishment with nitrogen was calculated based on the difference between the amount of nitrogen used by plants from the soil and its entry into the soil with root and post-harvest residues (Table. 1).
According to calculations using the Hopkins-Peters coefficient, it was determined that the amount of fixed nitrogen under clover was 32 kg/ha more than the same indicator under the narrow-leaf lupine on the control variant. Simultaneously, the average amount of fixed nitrogen under various fertilizer systems was 48 kg/ha more under clover than under lupine.
After clover with roots and residues, 166 kg/ha nitrogen remains under control and 204 kg/ha on average under various fertilizer systems. The loss of nitrogen by the soil is 95 kg/ha and 120 kg/ha, respectively. Consequently, clover enriches the soil with nitrogen in the control variant by 71 kg/ha, and on average in fertilized variants - by 84 kg/ha.

Table 1. Nitrogen accumulation in the soil in grain and grain-potato short crop rotations under clover and lupine crops, kg/ha.

Crops	Fertilizer systems	The total amount of nitrogen in a whole plant		Amount of nitrogen taken from the soil	Amount of nitrogen in root and post-harvest residues	Replenishment of soil with nitrogen by plants
		Total quantity	Including fixed nitrogen			
Narrow-leaflupine	Control (no fertilizer)	237	158	79	68.3	-10.7
	Averages for fertilizer systems	288	192	96	81.5	-14.5
Clover	Control (no fertilizer)	285	190	95	166	71
	Averages for fertilizer systems	360	240	120	204	84

According to the calculations, the whole plant of narrow-leaved lupine removes more nitrogen from the soil than its content in the roots and post-harvest residues by 10.7 kg/ha under control and by 14.5 kg/ha on average under various fertilized variants. Thus, narrow-leaf lupine does not enrich the soil with nitrogen if grown as a fodder crop in crop rotation, not as green manure.
Simultaneously, the supply of nitrogen to the soil with all crops of grain crop rotation was determined. We found that on average, for crop rotation with roots and post-harvest residues in the control variant, 82 kg/ha entered the soil, and on average for fertilizer systems,112 kg/ha of nitrogen. In the grain-potato crop rotation in the control variant and on average for fertilizer systems, nitrogen intake to the soil was 46 and 60 kg/ha, respectively. In the grain crop rotation, the nitrogen supply to the soil with post-harvest residues and roots was almost twice as high as in the grain-potato crop rotation.
The nitrogen intake level in the soil with fertilizers and fresh organic matter with roots and post-harvest residues determined the soil's nitrogen regime. Studies have shown that on average for grain crop rotation crops in the control variants, the easily hydrolyzed nitrogen reserves in the 0-20 cm layer were higher by 38 kg/ha or 24%, and mineral nitrogen - by 18 kg/ha or 47% higher than in grain-potato crop rotation. The same pattern can be traced in the average indicators on fertilized variants (Table. 2).
Regardless of the crop rotation type, traditional, organic, and alternative fertilizer systems positively affected soil reserves of hydrolyzed nitrogen. In the mineral system, due to the absence of organic components in the fertilizer system, the reserves of easily hydrolyzed nitrogen were even lower than in the control variants. Under the alternative system, mineral fertilizers and green manure reserves in the grain crop rotation were 17 kg/ha or 27% higher than under the traditional (10 t/ha of manure + NPK) fertilizer system. In the grain-potato crop rotation under the alternative fertilizer system, they were more than twice as high as under the traditional one - by 32 kg/ha (Table. 2).

Table 2. Nitrogen regime of sod-podzolic soil in grain-potato short crop rotation.

№	Fertilizer systems	Averages on grain crop rotation		Averages on grain-potato crop rotation	
		N easily hydrolyzed,kg/ha	$N\text{-}NO_3 + N\text{-}NH_4$, kg/ha	N easily hydrolyzed,kg/ha	$N\text{-}NO_3 + N\text{-}NH_4$, kg/ha
1	Control (no fertilizer)	160	37.5	122	19.8
2	Traditional (organic and mineral) fertilizer system (animal manure (10 t/ha) + NPK)	178	45.2	135	24.9
3	Mineral fertilizer system(NPK)	147	44.7	110	27.5
4	Organic fertilizer system (animal manure - 10 t/ha)	182	62.0	153	28.4
5	Alternative fertilizer system (NPK + green manure + by- products)	173	62.2	155	56.7
Averages		168	54.3	135	31.5

Studies have shown that the set of crops in crop rotations largely determines the removal of nitrogen with the crop. Thus, in the grain crop rotation, the crop yield's total removal was higher than in the grain-potato crop rotation - in control by 48 kg/ha, and the variants of fertilizer systems - by 90 kg/ha. In this case, the main difference is related to the removal of nitrogen by corn and potatoes. In the control variant, the overage of nitrogen removal by corn was 47 kg/ha, in fertilized variants - 78 kg/ha or 54% and 51%, respectively (Table. 3).

Table 3. Nitrogen removal with leadingproduct and by-products in short crop rotations under various fertilizer systems on sod-podzolic sandy loam soil (2007-2018), kg/ha.

Fertilizersystems	Grain croprotation					Grain-potato crop rotation				
	Clover	Winter wheat	Corn	Spring wheat	Total quantity	Narrow-leaf lupine	Winter rye	Potatoes	Hulless oat	Total quantity
Control (No fertilizer)	117	62	87	45	311	94	73	40	57	263
Averages for fertilized systems	156	99	154	89	498	142	103	76	87	408

The crop fertilization level carried out the calculation of the nitrogen balance in the fertilizer-crop system in crop rotation, symbiotic nitrogen fixation of clover and lupine, and removal with the main product and by-products on the variant with an alternative fertilizer system– removal only with the main products. The calculation of the nitrogen balance in the fertilizer-crop system in crop rotations included:1) crop fertilization level; 2) symbiotic nitrogen fixation of clover and lupine; 3) removal with the leadingproduct and by-products, on the variant with an alternative fertilizer system – removal only with the leadingproducts.)
The main expenditure component of nitrogen balance is the removal of nitrogen by the crop yield. Studies have shown that it is primarily determined by nitrogen removal by corn and potato. We determined that with the corn crop, 87 kg/ha of nitrogen is taken out in the control variant, on average for the variants - 154 kg/ha, which is 47 kg/ha and 78 kg/ha, respectively, or 54% and 51% more than the nitrogen removal by the potato crop. On average, in grain crop rotation, nitrogen removal in the control variant was 48 kg/ha higher than in the grain-potato crop rotation.

Table 4. Nitrogen balance in short crop rotations under various systems for restoring sod-podzolic soil fertility in 2007-2018.

Fertilizer systems	Grain crop rotation										Grain-potato crop rotation									
	Input, kg/ha				Output, kg/ha						Input, kg/ha				Output, kg/ha					
	Organic fertilizers	Mineral fertilizers	Nitrogen fixation + Seeds	Total quantity	Main product	By-products	Air + Leaching	Total quantity	Balance, kg	Balance intensity, %	Organic fertilizers	Mineral fertilizers	Nitrogen fixation + Seeds	Total quantity	Main product	By-products	Air + Leaching	Total quantity	Balance, kg	Balance intensity, %
Control (no fertilizer)	-	-	52.5	52.5	66.9	26.8	-	94	-41	56	-	-	44	44	46.2	23.1	-	69	-25	63
Organic and mineral (animal manure (10 t/ha) + NPK)	50	60	66.8	177	114	40.8	40	195	-18	91	50	60	52	162	82.8	35	40	158	4	103
Mineral (NPK)	-	60	59	119	100	35.7	30	166	-47	72	-	60	55	115	66.7	27.6	30	124	-9	93
Organic I (animal manure 10 t/ha)	50	-	67.8	118	103	35.8	15	154	-36	77	50	-	55	105	71	30	15	116	-11	91
Organic II (animal manure 10 t/ha)	100	-	73.3	173	120	41.8	20	182	-9	95	100	-	55	155	79.9	33.9	20	134	21	116
Alternative I (NPK + green manure)	28	60	60.8	149	103	40	35	178	-29	84	28	60	48	136	66	30.1	35	131	5	104
Alternative II (NPK + green manure + by-products)	65	60	74.8	200	125	-	40	165	35	121	58	60	56	174	87.9	-	40	128	46	136

The average nitrogen removal rate on fertilized grain crop rotation variantswas 90 kg/ha higher compared to similar data of grain-potato crop rotation.

Due to the significant removal of nitrogen by crop yield in grain crop rotation, its balance was more intense than in grain-potato one (Table. 4).

In the grain-potato crop rotation, the nitrogen balance was positive for organic II fertilizer system(with the input of 20 t/ha of manure) with a balanced intensity of 116% and both alternative fertilizer systems("green manure + NPK" and "green manure + by-products + NPK") with an intensity of 104% and 136%, respectively. In the grain crop rotation, a positive nitrogen balance was obtained only for the alternative II fertilizer system (green manure + by-products + NPK). The balance intensity, in this case, was 121%.

With by-products under the alternative II fertilizer system, 40 kg/ha of nitrogen is returned in the grain crop rotation, and 30 kg/ha in the grain- potato crop rotation, 24% and 23% of total nitrogen output.

Conclusion

We found that the soil's nitrogen regime is less stressful in the grain-potato short crop rotation with lupine for grain than in the grain short crop rotation with clover in the Left-Bank Ukraine (ChernihivPolissya). Nitrogen removal by the yield of grain short crop rotation with corn is 18-22% higher than the yield of grain-potato short crop rotation.

In the grain crop rotation for all fertilizer systems, except alternative, there is a negative nitrogen balance with an intensity of 91%, 95% for traditional (10 t/ha of manure + NPK), and organic (20 t/ha of manure), 72% for mineral. The intensity of nitrogen balance for alternative fertilizer systems (green manure + by-products + NPK) is 121%.

In the grain-potato crop rotation, the nitrogen balance was negative under the mineral fertilizer and organic I (10 t/ha of manure) – the intensity of 93% and 91%, respectively. The alternative II fertilizer system (green manure + by-products + NPK) provided the highest positive nitrogen balance of 135%.

Thus, in the conditions of the Left-Bank Chernihiv Polissya on sod-podzolic soil, the use of by-products as organic fertilizer is a significant reserve for replenishing the soil with organic matter and nitrogen.

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