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NITROGEN BALANCE IN THE LONG-TERM EXPERIMENTS ON THE LEACHED CHERNOZEM FROM CENTRAL ZONE OF THE REPUBLIC OF MOLDOVA

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Abstract

The article presents the results of nitrogen balance evaluation in long-term experiments on leached chernozem during the 1991-2020 years at the level of agricultural plants, crop rotation and fertilizer doses. It was established that the nitrogen balance in the control variant (without fertilizers) is profoundly negative, on average constituting 81 kg/ha. Manure in dose of 60 t/ha associated with vegetable residues applied in autumn 1990 led to the reduction of the negative balance by approximate 33 kg/ha. The administration of organo-mineral fertilizers led on average for 30 years to the reduction of the negative nitrogen balance compared to the control variant by 5-57 kg/ha annually. The organic fertilizers role in maintaining an equilibrated balance was essential in the fertilization system of agricultural crops. The nitrogen fertilizers application in doses of 30-90 kg/ha did not fully compensate this deficit, only in doses of 120-150 kg/ha of nitrogen fertilizers led to an almost equilibrated and even positive nitrogen balance in some years.

Key words*: balance, nitrogen, chernozem cambic, field, fertilization system.*

INTRODUCTION

The evaluation of soil fertility can be done through the direct method of agrochemical research of agricultural lands (Șimon, Russu, Ceclan, et al., 2022). The last agrochemical mapping of soils was carried out in 1990 by the State Agrochemical Service with its liquidation (Burlacu, 2000). Since then, the changes in nutritive elements circuit in the soils of Moldova are enormous, as a result of the drastic decrease in the application of fertilizers, as well as the changes in the sown crops structure (Andrieș, 2011; Donos, 2008; Лях Т. & Лях Н., 2012). However, what are the true extent of these changes and what is their impact on agriculture is not known. An agrochemical mapping of soils at the current stage cannot be carried out due to the lack of a specialized structure, as well as the very high costs for it. The balance of nutrients and humus is an indirect alternative method of assessing the soil fertility state in agriculture and is much cheaper. The first assessment of the biophilic elements and organic matter balance in Moldovan agriculture was carried out in the 90s and covered the period 1965-1990 (Andries, 2013; Zagorcea, 1989; Lungu, 1992). The nutrients balance is a numerical indicator of the changes in the reserves of biophilic elements in the soil in a year, or in a time period of years following their introduction or removal (Chiriță, Rusu, Urdă, et al., 2023). The agroecological and economic importance of the balance lies in the fact that it is a scientific criterion for establishing the forecast of the agricultural production level, as well as the need for fertilizers for it (Leonte, Isticioaia, Pintilie, et al., 2023; Marin, Kurtinetz, Sirbu, et al., 2023). Of great scientific and practical importance is the study of the balance in long-term experiments with fertilizers. They make possible an objective scientific evaluation of the main items of nutrients intake and consumption, since all calculations are performed on the analytical material itself (Lixandru et al., 1990; Madjar & Davidescu, 2008; Tkachenko, Zadubinna, Kondratiuk et al., 2023). The main objective of this work is to determine the nitrogen balance in long-term experiments on leached chernozem during the years 1991-2020 at the level of culture, fertilization system and fertilizer doses.

MATERIALS AND METHODS

The studies were carried out within the long-term experimental station of IPAPS "N.Dimo"

(Ivancea com., Orhei district, founded in 1964) on the clayey-loamy leached (cambic) chernozem. Humus content in the arable layer - 3.4%; aqueous pH - 6.8; $\sum Ca^{2+} + Mg^{2+}$ = 37.4 me/100 g soil. Since 2000, the resort has been registered in the EUROSOMNET international network (Andries et al., 2014).

The evaluation of the nitrogen balance in the experiments was carried out during the years 1991-2020 at the level of culture, rotation and fertilizers doses. During this period, the following field crops were grown in rotation: winter wheat and barley, grain corn, sunflower, leguminous crops (peas, beans, soybeans, alfalfa). The research was carried out on the first three field experiments with different fertilization systems of application: Experiment 1 - chemical fertilizer system; Experiment 2 - organo-mineral system (chemical fertilizers are applied on the basis of 60 t/ha of manure associated with plant residues); Experiment 3 - organo-mineral fertilization system (chemical fertilizers are administered on the basis of vegetable residues).

Organic fertilizers (manure) were applied in the autumn of 1990, 1995 and 2005 in dose of 60 t/ha, the mineral ones (NPK) after the previous crops, systematically (annually) during the basic soil work, in the periods of 1985 -1995 and 2006-2020. In the 1996-2005, their post-action was studied. The levels of mobile phosphorus in soil from 1.5-4.5 mg/100 g of soil (Macighin method - extracted in 1% ammonium carbonate in a ratio of 1:20, pH-9) were maintained by compensating the export of phosphorus by the previous crop.

Nitrogen doses (N): for winter wheat, corn for grains and alfalfa - 0, 30, 60, 90, 120 and 150 kg/ha in active substances (a.s.); for barley, sunflower and leguminous crops - 0, 30, 45, 60, 75 and 90 kg/ha. On the fond (background) with mobile phosphorus, the nitrogen doses were: for wheat and corn - N_{120}; alfalfa - N_{60}; barley and sunflower – N_{45}; peas, beans and soy - N_{30}. Consumption and intake items were used to calculate the balance (Donos & Andrieş, 2001; Метод. указания..., 1989; Mărin & Negrilă, 2022; Pintilie et al., 2023). The consumption items were: export with the harvest and secondary production, input items - mineral and organic fertilizers, and symbiotic nitrogen from leguminous crops.

RESULTS AND DISCUSSIONS

Experiment 1. The nitrogen balance in rotation with a system of applying mineral fertilizers on the leached chernozem is show in Table 1.

Table 1. Nitrogen balance (kg/ha) with the mineral fertilizer application system - Exp. 1

No.	Variant	Average over periods						
		1991-1995	1996-2000	2001-2005	2006-2010	2011-2015	2016-2020	**1991-2020**
1	Control	-147.8	-55.7	-78.7	-63.2	-80.7	-76.0	**-83.7**
2	Fond - 0	-	-	-	-	-	-	**-**
3	$N_{30\text{-}120}P_{1,0\text{-}1,5}K_{60}$	-173.3	-67.0	-89.6	4.7	-0.3	-12.9	**-56.4**
4	$N_{30\text{-}120}P_{1,5}K_{60}$	-216.4	-73.8	-96.0	-1.9	-19.3	-32.5	**-73.3**
5	$N_{30\text{-}120}P_{2,0}K_{60}$	-236.3	-76.7	-99.3	-14.6	-29.0	-52.7	**-84.8**
6	$N_{30\text{-}120}P_{2,5}K_{60}$	-246.9	-79.3	-101.7	-23.6	-36.2	-61.3	**-91.5**
7	$N_{30\text{-}120}P_{3,0}K_{60}$	-253.1	-79.4	-101.2	-30.0	-41.8	-66.2	**-95.3**
8	$N_{30\text{-}120}P_{3,5}K_{60}$	-258.0	-80.8	-104.9	-32.2	-45.9	-64.3	**-97.7**
9	$N_{30\text{-}120}P_{4,0}K_{60}$	-256.9	-82.7	-107.2	-29.6	-42.6	-60.5	**-96.6**
10	$N_{30\text{-}120}P_{4,5}K_{60}$	-256.4	-81.2	-108.2	-32.1	-41.2	-62.1	**-96.8**
11	$P_{3,0}K_{60}$	-261.0	-73.4	-103.2	-89.0	-109.8	-113.9	**-125.0**
12	$N_{30}P_{3,0}K_{60}$	-253.9	-77.8	-103.0	-68.2	-100.9	-99.7	**-117.3**
13	$N_{45\text{-}60}P_{3,0}K_{60}$	-254.2	-83.9	-107.3	-52.7	-85.4	-89.3	**-112.2**
14	$N_{60\text{-}90}P_{3,0}K_{60}$	-234.2	-88.5	-103.4	-32.8	-61.6	-70.6	**-98.5**
15	$N_{75\text{-}120}P_{3,0}K_{60}$	-226.1	-91.1	-109.4	-10.0	-38.0	-49.4	**-87.3**
16	$N_{90\text{-}150}P_{3,0}K_{60}$	-197.2	-90.0	-109.8	16.0	-8.0	-21.3	**-68.4**
17	$N_{30\text{-}120}P_{3,0}K_{120}$	-256.7	-84.5	-108.1	-31.0	-43.4	-63.7	**-97.9**
18	$N_{30\text{-}120}P_{3,0}K_{60}+Zn_{10}$	-269.0	-84.8	-107.0	-30.0	-42.4	-72.2	**-100.9**

As a research result, it was established that the average nitrogen balance for the period 1991-1995 on Exp. 1 where alfalfa was grown for 5 years is deeply negative. Even if we consider that the nitrogen export from the soil is only 40% and 60% symbiotic nitrogen from the atmosphere, the nitrogen balance remains negative, at the level of -59... -107 kg/ha.

In the post-action period of mineral fertilizers 1996-2005, the nitrogen balance remained profoundly negative, ranging from -56 to -109 kg/ha. The application of mineral fertilizers during the years 2006-2020 led to the reduction of the negative balance, from ... -114 kg/ha to a positive balance of ...+16 kg/ha (Table 1). Therefore, the annual average of the nitrogen balance on the field with a mineral fertilizer application system for the period 1991-2020 is deeply negative.

Experiment 2 with organo-mineral application system (on the background of 60 t/ha of manure associated with plant residues, mineral fertilizers were applied). The values of the nitrogen balance in rotation on the leached chernozem in Exp. 2 are presented in Table 2.

On the Exp. 2 from rotation, it was established that on the control variant, approximately 50-100 kg/ha of nitrogen is exported from the soil with the harvests, the average for the years 1991-2020 was 78 kg/ha.

Manure in a dose of 60 t/ha associated with vegetable residues applied in the autumn of 1990 led to the reduction of the negative balance by approximate 33 kg/ha.

The application of mineral fertilizers with nitrogen in doses of 30-90 kg/ha compensated this deficit with 9-51 kg/ha. On the variants with doses of 120-150 kg/ha, the nitrogen balance became positive. In the post action period of the fertilizers 2001-2005 the nitrogen balance was deeply negative, ranging from -85 to -121 kg/ha. The role of manure is obvious in stabilizing the nitrogen balance, given that in the autumns of 1990, 1995 and 2005, 60 t/ha of manure were applied.

The application of organo-mineral fertilizers led on average for 30 years to the reduction of the negative balance compared to the control variant by 5-57 kg/ha annually (Table 2).

Therefore, the role of organic fertilizers in maintaining a balanced balance is essential in the fertilization system of agricultural crops.

Table 2. Nitrogen balance (kg/ha) with the organo-mineral fertilizers application system - Exp. 2

No.	Variant	Average over periods						
		1991-1995	1996-2000	2001-2005	2006-2010	2011-2015	2016-2020	**1991-2020**
1	Control	-87.1	-61.5	-85.1	-50.5	-82.2	-100.8	**-77.8**
2	Fond (60 t/ha manure + plant residues)	-53.8	-21.3	-99.5	-34,6	-98.3	-115.6	**-70.5**
3	$N_{30\text{-}120}P_{1,0\text{-}1,5}K_{60}$	24.4	-28.7	-101,8	8.0	-28.8	-49.0	**-29.3**
4	$N_{30\text{-}120}P_{1,5}K_{60}$	21.9	-37.1	-106.7	-10.5	-36.5	-68.2	**-39.5**
5	$N_{30\text{-}120}P_{2,0}K_{60}$	18.6	-42.0	-107.7	-20.9	-41.2	-76.2	**-44,9**
6	$N_{30\text{-}120}P_{2,5}K_{60}$	17.0	-43.1	-114.7	-28.2	-44.6	-80.2	**-49.0**
7	$N_{30\text{-}120}P_{3,0}K_{60}$	13.8	-23.7	-117.4	-31.7	-45.6	-82.0	**-47.8**
8	$N_{30\text{-}120}P_{3,5}K_{60}$	18.2	-45.2	-116.0	-35.2	-47.6	-79.4	**-50.9**
9	$N_{30\text{-}120}P_{4,0}K_{60}$	15.8	-50.4	-115.9	-34.8	-48.6	-80.8	**-52.5**
10	$N_{30\text{-}120}P_{4,5}K_{60}$	13.0	-45.8	-116.3	-36.2	-49.2	-81.6	**-52.7**
11	$P_{3,0}K_{60}$	-63.0	-31.6	-107.6	-81.1	-107.1	-131.6	**-87.0**
12	$N_{30}P_{3,0}K_{60}$	-45.2	-37.6	-108.8	-47.3	-84.8	-115.1	**-73.1**
13	$N_{45\text{-}60}P_{3,0}K_{60}$	-27.9	-42.8	-117.3	-41.3	-74.9	-113.9	**-69.7**
14	$N_{60\text{-}90}P_{3,0}K_{60}$	-2.7	-47.1	-119.1	-18.7	-54.8	-97.5	**-56.6**
15	$N_{75\text{-}120}P_{3,0}K_{60}$	25.6	-48.7	-121.2	1.6	-30.9	-71.3	**-40.8**
16	$N_{90\text{-}150}P_{3,0}K_{60}$	59.0	-48.3	-112.3	27.0	-6.2	-42.8	**-20.6**
17	$N_{30\text{-}120}P_{3,0}K_{120}$	10.1	-46.8	-117.4	-33.6	-50.4	-82.1	**-53.4**
18	$N_{30\text{-}120}P_{3,0}K_{60}+Zn_{10}$	10.4	-46.5	-117.9	-37.7	-46.1	-79.2	**-52.8**

Experiment 3 with an organo-mineral fertilization system (mineral fertilizers were administered on the background of plant residues). As a research result, it was established that on the third field of the rotation in the control variant, approximately 51-119 kg/ha of nitrogen is exported from the soil with the harvests, the average for the years 1991-2020 is 81 kg/ha. The application of chemical fertilizers with nitrogen in doses of 30-90 kg/ha did not fully compensate this deficit, only in doses of 120-150 kg/ha the nitrogen balance became almost equilibrated and even positive in some years (Table 3).

Table 3. Nitrogen balance (kg/ha) with organo-mineral fertilizers the application system - Exp. 3

No.	Variant	Average over periods						
		1991-1995	1996-2000	2001-2005	2006-2010	2011-2015	2016-2020	**1991-2020**
1	Control	-82.1	-51.6	-84.4	-119.2	-82.0	-66.5	**-81.0**
2	Fond (vegetable residue)	-92.4	-65.5	-103.9	-172.5	-89.5	-75.7	**-99,9**
3	$N_{30\text{-}120}P_{1,0\text{-}1,5}K_{60}$	-19.6	-81.9	-114.5	-113.9	2.8	6.7	**-53.4**
4	$N_{30\text{-}120}P_{1,5}K_{60}$	-23.4	-88.2	-124.7	-120.8	-5.6	-119	**-62.4**
5	$N_{30\text{-}120}P_{2,0}K_{60}$	-38.4	-91.3	-136.3	-128.2	-17.8	-25.5	**-72.9**
6	$N_{30\text{-}120}P_{2,5}K_{60}$	-46.3	-95.9	-154.9	-135.9	-27.9	-36.5	**-82.9**
7	$N_{30\text{-}120}P_{3,0}K_{60}$	-49.2	-96.2	-156.9	-140.2	-31.5	-41.1	**-85.8**
8	$N_{30\text{-}120}P_{3,5}K_{60}$	-42.2	-95.9	-161.4	-141.1	-31.0	-45.1	**-86.1**
9	$N_{30\text{-}120}P_{4,0}K_{60}$	-52.9	-97.2	-163.6	-138.1	-29.3	-42.0	**-87.2**
10	$N_{30\text{-}120}P_{4,5}K_{60}$	-40.2	-98.6	-164.7	-138.0	-29.9	-44.4	**-85.9**
11	$P_{3,0}K_{60}$	-121.9	-85.3	-141.0	-202.3	-107.0	-98.5	**-126.0**
12	$N_{30}P_{3,0}K_{60}$	-108.9	-92.6	-147.2	-184.1	-89.1	-87.5	**-118.2**
13	$N_{45\text{-}60}P_{3,0}K_{60}$	-88.1	-95.8	-162.1	-167.6	-73.2	-76.9	**-110.6**
14	$N_{60\text{-}90}P_{3,0}K_{60}$	-60.2	-98.6	-163.5	-148.1	-52.3	-59.0	**-96,9**
15	$N_{75\text{-}120}P_{3,0}K_{60}$	-39.5	-102.3	-161.0	-123.7	-25.9	-36.7	**-81.5**
16	$N_{90\text{-}150}P_{3,0}K_{60}$	-11.1	-101.6	-157.5	-101.4	5.5	-6.4	**-62.1**
17	$N_{30\text{-}120}P_{3,0}K_{120}$	-56.1	-96.8	-154.0	-143.8	-31.6	-44.4	**-87.8**
18	$N_{30\text{-}120}P_{3,0}K_{60}+Zn_{10}$	-53.3	-96.6	-162.8	-139.7	-31.8	-43.2	**-87.9**

Winter wheat. It was established that in the control variant, approximately 50-70 kg/ha of nitrogen is exported from the soil with the autumn wheat harvests, the average for 1991-2020 being 62 kg/ha. The application of organic and mineral fertilizers with nitrogen led to the reduction of the negative balance compared to the control variant. Nitrogen fertilizers in doses of 30-90 kg/ha did not compensate this deficit, the balance becoming equilibrated or positive only at doses of 120-150 kg/ha of nitrogen. An improvement in the nitrogen balance is observed in fields with manure. In the post-action period of nitrogen fertilizers (1996-2005) the nitrogen balance is deeply negative, varying from -69 to -105 kg/ha. Considering that no nitrogen fertilizers were applied for ten years, we believe that doses of 120-150 kg/ha for wheat will ensure a balanced nitrogen balance. (Table 4).
Therefore, the application of organic and mineral fertilizers with nitrogen on the leached chernozem led to the reduction of the negative nitrogen balance for an average of 30 years.

Table 4. Nitrogen balance (kg/ha) at the growing of winter wheat on leached chernozem

No.	Variant	Average over periods						
		1991-1995	1996-2000	2001-2005	2006-2010	2011-2015	2016-2020	**1991-2020**
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
1	Control	-65.4	-49.6	-59.7	-60.2	-68.3	-70.5	**-62.3**
2	Fond*	-51.4	-57.0	-69.4	-51.0	-76.2	-92.3	**-66.2**
3	$N_{120}P_{1,0\text{-}1,5}K_{60}$	36.2	-73.3	-69.4	75.5	30.4	-7.6	**+1.2**
4	$N_{120}P_{1,5}K_{60}$	26.0	-80.2	-73.1	66.6	16.6	-18.7	**-10.5**
5	$N_{120}P_{2,0}K_{60}$	20.6	-82.9	-77.6	51.2	5.2	-38.2	**-20.3**

Continuation of Tab.4

1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
6	$N_{120}P_{2,5}K_{60}$	15.3	-87.3	-77.9	41.1	-2.8	-49.5	**-26.9**
7	$N_{120}P_{3,0}K_{60}$	14.4	-88.8	-84.4	34.4	-8.2	-54.3	**-31.2**
8	$N_{120}P_{3,5}K_{60}$	14.3	-90.3	-90.8	31.3	-10.2	-53.8	**-33.3**
9	$N_{120}P_{4,0}K_{60}$	13.9	-92.8	-92.3	32.6	-8.5	-51.8	**-33.2**
10	$N_{120}P_{4,5}K_{60}$	14.5	-92.8	-93.5	32.5	-8.6	-54.4	**-33.7**
11	$P_{3,0}K_{60}$	-77.7	-72.8	-80.6	-83.1	-93.5	-108.8	**-86.1**
12	$N_{30}P_{3,0}K_{60}$	-71.2	-81.9	-81.7	-65.0	-81.8	-103.7	**-80.9**
13	$N_{60}P_{3,0}K_{60}$	-46.3	-89.7	-89.9	-52.0	-59.9	-97.0	**-72.5**
14	$N_{90}P_{3,0}K_{60}$	-15.2	-98.3	-88.3	-23.5	-38.8	-80.7	**-57.5**
15	$N_{120}P_{3,0}K_{60}$	21.2	-103.6	-88.4	4.9	-9.1	-56.3	**-38.6**
16	$N_{150}P_{3,0}K_{60}$	56.0	-105.0	-84.5	38.5	25.8	-20.6	**-15.0**
17	$N_{120}P_{3,0}K_{120}$	11.6	-93.2	-91.0	8.0	-9.4	-56.1	**-38.4**
18	$N_{120}P_{3,0}K_{60}+Zn_{10}$	13.7	-93.0	-87.8	10.7	-9.5	-72.8	**-39.8**

***Note:** Field 1: Background - 0; Field 2: Background - 60 t/ha of manure + plant residues; Field 3: Background - plant residues.

Grain corn. It was established that in the control variant, approximately 77-105 kg/ha of nitrogen is exported from the soil with the corn harvest annually, the average for 1991-2020 being 94 kg/ha. The application of organic and mineral fertilizers with nitrogen led to the reduction of the negative balance compared to the control variant by 20-60 kg/ha of nitrogen.

Nitrogen fertilizers in doses of 30-90 kg/ha did not compensate this deficit, the balance becoming more equilibrated, even positive only at doses of 120-150 kg/ha of nitrogen. As in the case of wheat, if we consider that no nitrogen fertilizers were applied for 10 years, we consider that the dose of 120 kg/ha for grain corn can ensure a equilibrated nitrogen balance under this crop (Table 5).

Table 5. Nitrogen balance (kg/ha) at the growing of grain corn on leached chernozem

No.	Variant	Average over periods						
		1991-1995	1996-2000	2001-2005	2006-2010	2011-2015	2016-2020	**1991-2020**
1	Control	-101.1	-77.2	-88.8	-83.2	-102.7	-105.5	**-94.4**
2	Fond*	-98.5	-50.2	-	-106.7	-110.4	-111.9	**-92.3**
3	$N_{120}P_{1,0\text{-}1,5}K_{60}$	15.8	-63.4	-89.6	1.3	-11.7	-17.5	**-24.6**
4	$N_{120}P_{1,5}K_{60}$	13.8	-69.6	-93.0	-8.5	-25.1	-25.3	**-32.2**
5	$N_{120}P_{2,0}K_{60}$	-5.7	-73.5	-94.6	-8.8	-32.8	-34.8	**-40.6**
6	$N_{120}P_{2,5}K_{60}$	-12.7	-76.1	-92.4	-8.2	-37.8	-39.0	**-44.5**
7	$N_{120}P_{3,0}K_{60}$	-18.1	-47.9	-93.8	-10.8	-36.3	-44.0	**-39.2**
8	$N_{120}P_{3,5}K_{60}$	-1.9	-75.8	-94.1	-5.7	-38.1	-45.0	**-43.5**
9	$N_{120}P_{4,0}K_{60}$	-20.2	-81.7	-92.7	10.2	-36.3	-43.1	**-46.5**
10	$N_{120}P_{4,5}K_{60}$	-3.8	-75.8	-96.3	10.5	-35.2	-44.1	**-42.1**
11	$P_{3,0}K_{60}$	-118.2	-68.5	-99.4	-125.4	-130.2	-132.7	**-110.8**
12	$N_{30}P_{3,0}K_{60}$	-105.0	-71.1	-97.2	-99.4	-113.0	-111.9	**-99.0**
13	$N_{60}P_{3,0}K_{60}$	-84.6	-74.8	-97.4	-71.3	-98.6	-97.4	**-88.0**
14	$N_{90}P_{3,0}K_{60}$	-50.1	-75.7	-94.9	-38.8	-67.3	-73.2	**-67.2**
15	$N_{120}P_{3,0}K_{60}$	-27.8	-78.2	-96.9	-11.3	-39.4	-45.4	**-49.9**
16	$N_{150}P_{3,0}K_{60}$	10.1	-75.9	-98.0	21.5	-5.2	-13.7	**-25.7**
17	$N_{120}P_{3,0}K_{120}$	-25.1	-74.4	-98.0	-8.0	-39.2	-45.2	**-48.2**
18	$N_{120}P_{3,0}K_{60}+Zn_{10}$	-24.4	-75.9	-96.6	-6.0	-37.8	-8.3	**-41.0**

***Note:** Field 1: Background - 0; Field 2: Background - 60 t/ha of manure + plant residues; Field 3: Background - plant residues.

Sunflower. According to the research, it was established that with the sunflower harvests in the control variant, approximately 32-97 kg/ha of nitrogen was exported from the soil annually, the average for the period 1991-2020 being 70 kg/ha.

The application of mineral fertilizers with nitrogen in doses of 30-60 kg/ha did not compensate for this deficit in the researched variants, the nitrogen balance being negative during the entire research period. An improvement the balance was obtained during the years 2006-2010 from the dose of 75- 90 kg/ha of nitrogen. Considering that no nitrogen fertilizers were applied for ten years, we can consider that the dose of 75 kg/ha for sunflower can ensure a equilibrated nitrogen balance (Table 6).

Table 6. Nitrogen balance (kg/ha) at the growing of sunflower on leached chernozem

No.	Variant	Average over periods						
		1991-1995	1996-2000	2001-2005	2006-2010	2011-2015	2016-2020	**1991-2020**
1	Control	-95.6	-31.7	-96.8	-47.2	-74.6	-69.2	**-70.0**
2	Fond*	-87.4	29.4	-121.3	-69.9	-90.0	-88.5	**-77.2**
3	$N_{45}P_{1,0\text{-}1,5}K_{60}$	-47.0	-15.7	-108.1	-11.8	-45.7	-42.8	**-45.2**
4	$N_{45}P_{1,5}K_{60}$	-45.1	-25.7	-110.6	-15.9	-50.4	-63.9	**-51.7**
5	$N_{45}P_{2,0}K_{60}$	-53.2	-31.8	-116.9	-21.3	-57.9	-78.8	**-59.7**
6	$N_{45}P_{2,5}K_{60}$	-56.3	-30.6	-120.3	-27.4	-66.6	-87.3	**-65.0**
7	$N_{45}P_{3,0}K_{60}$	-59.5	-33.0	-121.3	-30.1	-72.0	-90.0	**-68.3**
8	$N_{45}P_{3,5}K_{60}$	-55.1	-28.6	-120.3	-32.8	-74.6	-89.0	**-67.8**
9	$N_{45}P_{4,0}K_{60}$	-61.0	-31.3	-122.3	-34.0	-73.7	-86.8	**-69.0**
10	$N_{45}P_{4,5}K_{60}$	-60.2	-30.1	-122.3	-35.7	-74.8	-89.2	**-69.6**
11	**$P_{3,0}K_{60}$**	-104.2	-20.6	-116.9	-67.8	-102.4	-97.8	**-87.4**
12	$N_{30}P_{3,0}K_{60}$	-83.5	-25.4	-118.8	-47.1	-80.1	-85.0	**-74.3**
13	$N_{45}P_{3,0}K_{60}$	-65.1	-29.8	-120.1	-30.8	-73.2	-87.1	**-68.5**
14	$N_{60}P_{3,0}K_{60}$	-46.9	-32.3	-122.3	-18.3	-60.3	-71.6	**-58.8**
15	$N_{75}P_{3,0}K_{60}$	-24.9	-29.4	-123.0	0.2	-44.3	-56.3	**-46.0**
16	$N_{90}P_{3,0}K_{60}$	-1.1	-29.1	-123.5	12.3	-27.4	-37.7	**-33.4**
17	$N_{45}P_{3,0}K_{120}$	-67.6	-31.5	-120.3	-32.5	-75.3	-86.1	**-69.8**
18	$N_{45}P_{3,0}K_{60}+Zn_{10}$	-66.3	-33.1	-124.0	-28.9	-72.7	-123.3	**-74.4**

***Note:** Field 1: Background - 0; Field 2: Background - 60 t/ha of manure + plant residues; Field 3: Background - plant residues.

Peas + soybeans + beans. It was established that in the control variant, approximately 21-59 kg/ha of nitrogen was exported from the soil with the grain pea harvests, the average for 1991-2020 being approximately 41 kg/ha. The application of mineral fertilizers 30-90 kg/ha during the years 1991-1995, when leguminous crops were grown on fields two and three with organo-mineral fertilizer application systems compensated this deficit, the balance becoming equilibrated or positive. On average over 1991-2020, the applied nitrogen doses did not ensure a equilibrated nitrogen balance. Considering that no nitrogen fertilizers were applied for ten years, we can say that nitrogen doses of 60-75 kg/ha will ensure a positive balance in the cultivation of legumes (Table 7).

Lucerne. As a result, it was established that the nitrogen balance for the entire period of 1991-2010 was negative. On the control variant, approximately 22-148 kg/ha of nitrogen is exported from the soil with alfalfa, the average being 72 kg/ha. During the 2006-2010, on the second field in the rotation with the organo-mineral fertilization system (60 t/ha of manure + plant residues), the application of nitrogen fertilizers led to the reduction of the negative nitrogen balance on some variants, up to 92% (Table 8). Therefore, the role of organo-mineral fertilizers in maintaining a balanced nitrogen balance is important in the alfalfa fertilization system.

Table 7. Nitrogen balance (kg/ha) at the growing of legumes (peas + soybeans + beans) on leached chernozem

No.	Variant	Average over periods						
		1991-1995	1996-2000	2001-2005	2006-2010	2011-2015	2016-2020	**1991-2020**
1	Control	-21.2	-30.8	-59.3	-47.9	-	-48.1	**-41.5**
2	Fond*	-20.7	-20.3	-97.0	-31.7	-	-	**-42.4**
3	$N_{30}P_{1,0\text{-}1,5}K_{60}$	10.2	-25.1	-78.1	-36.0	-	-22.0	**-30.2**
4	$N_{30}P_{1,5}K_{60}$	9.3	-30.0	-85.6	-40.6	-	-47.6	**-38.9**
5	$N_{30}P_{2,0}K_{60}$	9.3	-32.8	-87.1	-48.3	-	-60.0	**-43.8**
6	$N_{30}P_{2,5}K_{60}$	9.3	-34.4	-110.7	-59.5	-	-63.0	**-51.7**
7	$N_{30}P_{3,0}K_{60}$	2.2	-35.3	-101.2	-65.1	-	-66.1	**-53.1**
8	$N_{30}P_{3,5}K_{60}$	0.5	-36.7	-97.0	-67.0	-	-58.6	**-51.8**
9	$N_{30}P_{4,0}K_{60}$	0	-37.0	-101.5	-67.7	-	-56.9	**-52.6**
10	$N_{30}P_{4,5}K_{60}$	0.5	-37.2	-97.5	-67.7	-	-53.3	**-51.0**
11	$P_{3,0}K_{60}$	-22.0	-32.7	-90.8	-80.5	-	-79.8	**-61.2**
12	$N_{30}P_{3,0}K_{60}$	6.2	-37.0	-93.5	-61.7	-	-52.5	**-47.7**
13	$N_{45}P_{3,0}K_{60}$	14.6	-39.7	-101.9	-46.9	-	-41.4	**-43.1**
14	$N_{60}P_{3,0}K_{60}$	33.1	-40.3	-101.9	-22.3	-	-31.7	**-32.6**
15	$N_{75}P_{3,0}K_{60}$	49.0	-44.0	-97.9	4.5	-	-14.5	**-20.6**
16	$N_{90}P_{3,0}K_{60}$	63.1	-42.2	-95.3	29.2	-	6.2	**-7.8**
17	$N_{30}P_{3,0}K_{120}$	-0.4	-42.0	-101.9	-84.0	-	-56.9	**-57.0**
18	$N_{30}P_{3,0}K_{60}+Zn_{10}$	4.0	-39.4	-100.5	-81.8	-	-58.6	**-55.3**

***Note:** Field 1: Background - 0; Field 2: Background - 60 t/ha of manure + plant residues; Field 3: Background - plant residues.

Table 8. Nitrogen balance (kg/ha) at the growing alfalfa on leached chernozem

No.	Variant	Average over periods						
		1991-1995	1996-2000	2001-2005	2006-2010	2011-2015	2016-2020	**1991-2020**
1	Control	-147.8	-21.9	-76.3	-41.0	-	-	**-71.8**
2	Fond*	-	-41.0	-101.0	-28.3	-	-	**-56.8**
3	$N_{60}P_{1,0\text{-}1,5}K_{60}$	-173.3	-51.0	-117.6	-3.3	-	-	**-86.3**
4	$N_{60}P_{1,5}K_{60}$	-216.4	-64.7	-132.1	-23.6	-	-	**-109.2**
5	$N_{60}P_{2,0}K_{60}$	-236.3	-69.2	-141.4	-36.1	-	-	**-120.8**
6	$N_{60}P_{2,5}K_{60}$	-246.9	-76.5	-161.0	-43.2	-	-	**-131.9**
7	$N_{60}P_{3,0}K_{60}$	-253.1	-79.2	-162.0	-47.5	-	-	**-135.5**
8	$N_{60}P_{3,5}K_{60}$	-258.0	-77.4	-165.4	-50.9	-	-	**-137.9**
9	$N_{60}P_{4,0}K_{60}$	-256.9	-77.4	-169.5	-49.8	-	-	**-138.4**
10	$N_{60}P_{4,5}K_{60}$	-256.4	-79.2	-170.4	-52.0	-	-	**-139.5**
11	**$P_{3,0}K_{60}$**	-261.0	-64.7	-146.5	-79.3	-	-	**-137.9**
12	$N_{30}P_{3,0}K_{60}$	-253.9	-74.7	-152.9	-66.1	-	-	**-136.9**
13	$N_{60}P_{3,0}K_{60}$	-254.3	-76.5	-168.8	-57.7	-	-	**-139.3**
14	$N_{90}P_{3,0}K_{60}$	-234.2	-81.0	-168.9	-29.3	-	-	**-128.4**
15	$N_{120}P_{3,0}K_{60}$	-226.1	-79.2	-171.6	-5.7	-	-	**-120.7**
16	$N_{150}P_{3,0}K_{60}$	-197.2	-76.5	-172.0	23.4	-	-	**-105.6**
17	$N_{60}P_{3,0}K_{120}$	-256.7	-77.4	-158.2	-27.5	-	-	**-130.0**
18	$N_{60}P_{3,0}K_{60}+Zn_{10}$	-269.0	-79.2	-170.5	-32.7	-	-	**-137.9**

***Note:** Field 1: Background - 0; Field 2: Background - 60 t/ha of manure + plant residues; Field 3: Background - plant residues.

According to the results on the leached chernozem, it was established that the organo-mineral fertilization led to the reduction of the negative nitrogen balance compared to the control version. When cultivating winter wheat and grain corn, the application of nitrogen

fertilizers in doses of 120-150 kg/ha compensated this deficit, the nitrogen balance becoming balanced or even positive.
When cultivating the sunflower, the nitrogen balance was negative throughout the research period. A reduction of the negative balance up to 33-46 kg/ha of nitrogen was also obtained from nitrogen fertilizers in a dose of 75-90 kg/ha administered annually. For the leguminous crops and alfalfa, the average nitrogen balance for the 1991-2020 period was deeply negative (Table 8).

CONCLUSIONS

1. *The comparative analysis of the nitrogen balance in different fertilization systems* established that on the leached chernozem the nitrogen balance on all three fertilization systems during the period 1991-2020 was deeply negative. It was established that the nitrogen balance in the control variant (without fertilizers) is profoundly negative, on average constituting - 81 kg/ha. On the second field in the rotation with an organo-mineral system (60 t/ha of manure + vegetable residues) the application of fertilizers led to the reduction of the negative nitrogen balance by 6-27% on the $N_{30\text{-}90}P_{3.0}K_{60}$ variants and by 32-73% on the variants with doses of 120-150 N-kg/ha. The role of organic fertilizers in the fertilization system of agricultural crops in maintaining a equilibrated nitrogen balance was significant.
2. *The comparative analysis of the nitrogen balance under the rotation crops* showed that the administration of organo-mineral fertilizers under the rotation crops led on average for 30 years to the reduction of the negative nitrogen balance by 5-57 kg/ha annually compared to the control variant. At the cultivating winter wheat and grain corn, the application of nitrogen fertilizers in doses of 120-150 kg/ha compensated this deficit, the nitrogen balance becoming equilibrated or positive. At the cultivating the sunflower, the nitrogen balance was negative throughout the research period. A reduction of the negative balance up to 33-46 kg/ha of nitrogen was obtained from nitrogen fertilizers in dose of 75-90 kg/ha a.s. applied annually. When growing leguminous crops and alfalfa, the average nitrogen balance for the period 1991-2020 was deeply negative.

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