Scientific Papers. Series A. Agronomy, Vol. LXVIII, No. 2, 2025
ISSN 2285-5785; ISSN CD-ROM 2285-5793; ISSN Online 2285-5807; ISSN-L 2285-5785

PHOSPHORUS BALANCE IN LONG-TERM EXPERIMENTS ON THE LEACHED CHERNOZEM WITH DIFFERENT FERTILIZATION SYSTEM

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Abstract

The article presents the results of the phosphorus balance assessment in long-term experiments on leached chernozem during 1991-2020 yrs. at the level of agricultural plants, crop rotation and fertilization system. It was established that the phosphorus balance in the control variant (without fertilizers) was negative throughout the research period, on average constituting minus 30.5 kg/ha. The application of phosphorus fertilizers in doses of 45 kg/ha on the field with mineral application system it almost equilibrated the phosphorus balance, with a negative balance, on average over 30 years, from minus 1.3 to minus12.9 kg/ha annually. Organic-mineral fertilizers led to an increase in the productivity of field crops and a decrease in the negative phosphorus balance in the crop rotation, on average by 19.7-36.1 kg/ha compared to the unfertilized variant. At the growing of winter wheat, corn for grains, sunflower and leguminous crops on leached chernozem, the application of phosphorus fertilizers at a dose of 45 kg/ha compensated the phosphorus deficit, the balance becoming equilibrated or positive.

Key words*: phosphorus balance, field crops, fertilization level, leached chernozem.*

INTRODUCTION

The nutrient cycle changes in the soils of the Republic Moldova are very large, as a result of the drastic decrease of fertilizers application, as well as changes in the structure of sown agricultural crops (Andrieș, 2011; 2016; Leah et al., 2013; Lungu, 2024).

The extent of these changes and their impact on present and future agriculture is not known today. The last round of agrochemical mapping of soils (in order to know the nutrient content in soils) was carried out in 1990 by the State Agrochemical Service (Burlacu, 2000). An agrochemical mapping of soils at the current stage cannot be carried out, the reason being the lack of a specialized structure, as well as the very high costs for it.

The nutrient balance can serve as an indirect alternative method for assessing the state of soil fertility in agriculture, and at the same time a less expensive one (Lixandru et al., 1990; Zagorcea, 1989; Лунгу, 1992). The dynamic determination of the nutrient balance state in the soil highlights the quantitative changes in the income and consumption items when growing agricultural crops. The first assessment of the balance of biophilic elements and humus in Moldovan agriculture was carried out in 1990s and covered the period 1965-1990 (Andries, 2013; Zagorcea, 1989; Лунгу, 1992; Лях, Т. & Лях Н, 2012).

The agroecological and economic importance of the phosphorus balance lies in the fact that it is a scientific criterion for establishing the forecast of the level of agricultural production, as well as the need for fertilizers for it.

Of great scientific and practical importance is the study of the phosphorus balance in long-term fertilizer field experiments. They make it possible to carry out an objective scientific assessment of the main items of nutrient input and consumption, since all calculations are carried out on the analytical material accumulated over the years (Lixandru et al., 1990; Madjar & Davidescu, 2008).

The main objective of this study is to determine the phosphorus balance in leached chernozem in long-term experiments depending on the fertilization system and fertilizer doses applied to field crops over a period of 30 years.

MATERIALS AND METHODS

The studies were carried out within the long-term experimental station of Institute of Pedology,

Agrochemistry and Soil Protection "Nicolae Dimo" (Ivancea commune, Orhei district), founded in 1964 on loamy-clayey leached chernozem. The humus content in the arable layer of soil - 3.4%; pHH_2O - 6.8; $\sum Ca^{2+} + Mg^{2+}$ = 37.4 me/100 g soil. Since 2000, the station has been registered in the European Database of long-term experiments on soil organic matter - EuroSOMNET (Andries, Lungu, Leah, 2014; Uwe Franko et al., 2002).

The evaluation of the phosphorus balance in experiments was carried out during the period 1991-2020. The following field crops were cultivated in rotation during this period: winter wheat and barley, corn for grains, sunflower, leguminous crops (peas, beans, soybeans, alfalfa). The research was carried out on three fields with the following fertilization systems: *Field 1* – mineral fertilizer system; *Field 2* – organic-mineral system (mineral fertilizers are applied on the basis of 60 t/ha of manure associated with plant residues); *Field 3* – organic-mineral system (mineral fertilizers are applied on the basis of plant residues).

Organic fertilizers (manure) were applied in the autumn of 1990, 1995 and 2005 at a dose of 60 t/ha, chemical fertilizers (NPK*) after the preceding crops, annually, during the basic soil work, in the periods of 1985-1995 and 2006-2020 (*K* - is not applied in from 2010*). In 1996-2005, their post-action was studied.

The levels of mobile phosphorus in the soil were within the limits of 1.5-4.5 mg/100 g of soil (*Macighin method - extracted in a 1% ammonium carbonate solution in a ratio of 1:20, pH-9*). These were maintained by compensating for the export of phosphorus from the preceding crop at a dose of 45 kg/ha.

The nitrogen (N) doses on the $P_{3.0}K_{60}$ basis were: for winter wheat, corn for grains and alfalfa - 0, 30, 60, 90, 120, 150 kg/ha in active substance (a.s); barley, sunflower and leguminous crops - 0, 30, 45, 60, 75, 90 kg/ha a.s. On the basis of mobile phosphorus ($P_{1.5-4.5}$) the nitrogen doses were: for winter wheat and corn - N_{120}; alfalfa - N_{60}; barley and sunflower - N_{45}; peas, beans and soybeans - N_{30}.

The phosphorus balance (BP_2O_5) was calculated on fertilization systems and crops according to the formula: $BP_2O_5 = (P_2O_5$ *input* $- P_2O_5$ *export),* where: P_2O_5 *input* - the phosphorus input with mineral and organic fertilizers; P_2O_5 *export* is the phosphorus export with the harvest and secondary production (Donos, Andrieş, 2001; Методические. ...., 1989).

RESULTS AND DISCUSSIONS

Field 1: *Mineral fertilizer application system on the leached chernozem.* The phosphorus balance values in crop rotation on the Field 1 is presented in Table 1.

Table 1. Phosphorus balance in the mineral fertilizer application system, kg/ha (Field 1)

No.	Variant	Average over periods						
		1991-1995	1996-2000	2001-2005	2006-2010	2011-2015	2016-2020	**1991-2020**
1	Control (unfertilized)	-58.7	-21.9	-29.5	-27.7	-29.2	-28.4	**-32.6**
2	Fond - 0	-	-	-	-	-	-	**-**
3	$N_{30-120}P_{1.0-1.5}K_{60}$	-39.1	+19.1	+11.7	+11.9	+8.3	+8.0	**+3.3**
4	$N_{30-120}P_{1.5}K_{60}$	-51.8	+16.7	+9.4	+8.9	+1.4	+1.3	**-2.4**
5	$N_{30-120}P_{2.0}K_{60}$	-57.8	+15.7	+8.3	+4.1	-2.1	-5.9	**-6.3**
6	$N_{30-120}P_{2.5}K_{60}$	-60.9	+14.8	+8.0	+0.4	-4.7	-9.0	**-8.6**
7	$N_{30-120}P_{3.0}K_{60}$	-62.7	+14.8	+7.7	-2.0	-6.8	-10.7	**-10.0**
8	$N_{30-120}P_{3.5}K_{60}$	-64.2	+14.3	+6.4	-2.9	-8.3	-10.1	**-10.8**
9	$N_{30-120}P_{4.0}K_{60}$	-63.9	+13.6	+5.6	-1.6	-7.1	-8.8	**-10.4**
10	$N_{30-120}P_{4.5}K_{60}$	-63.7	+14.1	+5.2	-3.0	-6.6	-9.4	**-10.6**
11	$P_{3.0}K_{60}$	-47.3	+17.0	+6.9	+6.8	+5.3	+3.3	**-1.3**
12	$N_{30}P_{3.0}K_{60}$	-54.1	+15.4	+7.1	+3.4	-2.4	-2.4	**-5.5**
13	$N_{45-60}P_{3.0}K_{60}$	-63.1	+13.2	+5.5	0.0	-6.3	-7.3	**-9.7**
14	$N_{60-90}P_{3.0}K_{60}$	-66.0	+11.5	+6.9	-2.1	-7.2	-9.1	**-11.0**
15	$N_{75-120}P_{3.0}K_{60}$	-72.5	+10.7	+4.8	-2.5	-8.1	-10.1	**-12.9**
16	$N_{90-150}P_{3.0}K_{60}$	-72.8	+11.1	+4.7	-1.7	-6.8	-8.7	**-12.4**
17	$N_{30-120}P_{3.0}K_{120}$	-63.8	+13.0	+5.3	-2.6	-7.4	-9.9	**-10.9**
18	$N_{30-120}P_{3.0}K_{60}$+Zn_{10}	-67.4	+12.9	+3.6	-2.2	-7.0	-13.2	**-12.2**

As a research result, it was established that the average phosphorus balance in the period 1991-1995 (5 years) on the Field 1, where alfalfa was cultivated, is deeply negative.

During the years in the control variant, where since 1964 no fertilizers have been applied, the phosphorus balance is negative ranging from -21,9 to -58,7 kg/ha, the average for the period 1991-2020 being minus 32,6 kg/ha.

The application of mineral fertilizers in crop rotation led to a decrease in the negative balance, from minus 39,1...-72,8 kg/ha to a equilibrated and even positive balance of +19,1 kg/ha (Table 1).

Therefore, the annual average phosphorus balance on the field with a mineral fertilizer application system for 1991-2020 period is almost equilibrated, from positive (+3.3) to negative (-1.3...-12.9 kg/ha).

Field 2: *Organic-mineral system (mineral fertilizers was application on the basis of 60 t/ha of manure associated with plant residues)*. The phosphorus balance on the Field 2 in crop rotation on the soil are presented in Table 2.

Table 2. Phosphorus balance in the organic-mineral fertilizer application system, kg/ha (Field 2)

No.	Variant	Average over periods						
		1991-1995	1996-2000	*2001-2005	2006-2010	*2011-2015	*2016-2020	**1991-2020**
1	Control	-31.2	-24.4	-31.2	-28.0	-29.3	-36.4	**-30.1**
2	Fond (60 t/ha manure + vegetable residue)	-4.8	+4.4	-35.8	-5.5	-35.1	-41.8	**-19.8**
3	Fond+$N_{30-120}P_{1.0-1.5}K_{60}$	-10.0	+1.8	+8.4	-10.8	+6.8	-7.1	**-1.8**
4	Fond+$N_{30-120}P_{1.5}K_{60}$	-11.0	-1.3	+6.9	-16.4	+4.1	-14.1	**-5.3**
5	Fond+$N_{30-120}P_{2.0}K_{60}$	-12.2	-3.0	+6.5	-19.6	+2.5	-17.0	**-7.1**
6	Fond+$N_{30-120}P_{2.5}K_{60}$	-12.7	-3.5	+4.3	-21.8	+1.2	-18.4	**-8.5**
7	Fond+$N_{30-120}P_{3.0}K_{60}$	-13.9	+4.4	+3.5	-22.9	+0.9	-19.1	**-7.9**
8	Fond+$N_{30-120}P_{3.5}K_{60}$	-12.3	-4.2	+3.9	-24.0	+0.2	-18.1	**-9.1**
9	Fond+$N_{30-120}P_{4.0}K_{60}$	-13.2	-6.3	+3.9	-23.9	-0.2	-18.6	**-9.7**
10	Fond+$N_{30-120}P_{4.5}K_{60}$	-14.2	-4.4	+3.7	-24.3	-0.4	-18.9	**-9.8**
11	Fond+$P_{3.0}K_{60}$	-8.0	+0.7	+6.6	-19.7	+6.7	-2.6	**-2.7**
12	Fond+$N_{30}P_{3.0}K_{60}$	-12.4	-1.5	+6.2	-22.2	+4.0	-7.5	**-5.6**
13	Fond+$N_{45-60}P_{3.0}K_{60}$	-14.8	-3.3	+3.5	-25.8	+0.1	-16.2	**-9.4**
14	Fond+$N_{60-90}P_{3.0}K_{60}$	-14.4	-4.8	+2.9	-24.4	-0.3	-19.3	**-10.1**
15	Fond+$N_{75-120}P_{3.0}K_{60}$	-12.8	-5.4	+2.0	-23.7	+0.7	-18.8	**-9.7**
16	Fond+$N_{90-150}P_{3.0}K_{60}$	-9.4	-5.3	+4.9	-21.4	+2.1	-17.5	**-7.8**
17	Fond+$N_{30-120}P_{3.0}K_{120}$	-15.2	-4.8	+3.4	-23.4	-0.8	-19.1	**-10.0**
18	Fond+$N_{30-120}P_{3.0}K_{60}$+Zn_{10}	-15.1	-4.7	+3.2	-24.6	+0.7	-18.1	**-9.8**

**Post-action period of manure greater than 5 years.*

On the Field 2 was established that in the control variant, approximately 24-36 kg/ha of phosphorus is annually exported from the soil with the crops, the average for 1991-2020 years being 30.1 kg/ha (Table 2). The application of manure in dose of 60 t/ha in the autumns of 1990, 1995 and 2005 associated with plant residues for the next 5 consecutive years led to a decrease in the negative phosphorus balance by approximately 22-29 kg/ha. During the 2001-2005, 2011-2015, 2016-2020 of post-action of manure, the phosphorus balance became negative, almost equalling with the unfertilized variant.

Manure in a dose of 60 t/ha maintained a equilibrated phosphorus balance over a 5-year period. The mineral phosphorus fertilizers administration in doses of 45 kg/ha on the basis of manure led to an increase in field crop yields, while also reducing the negative phosphorus balance to -3...-10 kg/ha, on average over 30-year period (Table 2).

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

Field 3: *Organic-mineral fertilization system (mineral fertilizers were administered on the basis of plant residues).* As a research result, it was established that on the Field 3 of the rotation in the control variant, approximately 23-38 kg/ha of phosphorus is annually exported with the crops, the average for the years 1991-2020 being 28.9 kg/ha. On the plant residues basis,

due to the higher yields, the phosphorus balance was negative throughout the research period, the average being 4,1 kg/ha higher than on the control variant (Table 3). The mineral fertilizers application with phosphorus in doses of 45 kg/ha compensated this deficit, the phosphorus balance becoming almost equilibrated and even positive in some years. Mineral fertilizers on the plant residues basis led to an increase in the crop productivity of rotation and a decrease in the negative phosphorus balance, on average by 23.8-36.1 kg/ha compared to the unfertilized variant (Table 3).

Table 3. Phosphorus balance with the organic-mineral fertilizer application system, kg/ha (Field 3)

No.	Variant	Average over periods						
		1991-1995	1996-2000	2001-2005	2006-2010	2011-2015	2016-2020	**1991-2020**
1	Control	-30.8	-24.0	-38.5	-26.9	-29.7	-23.3	**-28.9**
2	Fond (vegetable waste)	-34.6	-28.7	-44.2	-31.4	-32.4	-26.6	**-33.0**
3	Fond+$N_{30-120}P_{1.0-1.5}K_{60}$	+5.3	+10.4	-2.2	+9.4	+8.0	+12.2	**+7.2**
4	Fond+$N_{30-120}P_{1.5}K_{60}$	+3.9	+8.3	-5.1	+6.9	+5.0	+5.6	**+4.1**
5	Fond+$N_{30-120}P_{2.0}K_{60}$	-1.5	+7.2	-8.8	+4.3	+0.6	+0.8	**+0.4**
6	Fond+$N_{30-120}P_{2.5}K_{60}$	-4.3	+5.6	-14.6	+1.6	-3.1	-3.0	**-3.0**
7	Fond+$N_{30-120}P_{3.0}K_{60}$	-5.2	+5.6	-15.3	+0.1	-4.4	-4.7	**-4.0**
8	Fond+$N_{30-120}P_{3.5}K_{60}$	-2.7	+5.6	-16.7	-0.2	-4.2	-6.1	**-4.1**
9	Fond+$N_{30-120}P_{4.0}K_{60}$	-6.5	+5.2	-17.3	+0.9	-3.6	-5.0	**-4.4**
10	Fond+$N_{30-120}P_{4.5}K_{60}$	-2.0	+4.7	-17.6	+1.0	-3.8	-5.8	**-3.9**
11	Fond+$P_{3.0}K_{60}$	-0.2	+9.3	-10.3	+6.1	+6.3	+10.6	**+3.6**
12	Fond+$N_{30}P_{3.0}K_{60}$	-6.3	+6.8	-12.2	+1.9	+1.9	+3.9	**-0.7**
13	Fond+$N_{45-60}P_{3.0}K_{60}$	-7.3	+5.7	-16.8	-0.2	-2.1	-1.3	**-3.7**
14	Fond+$N_{60-90}P_{3.0}K_{60}$	-6.0	+4.7	-17.3	-1.3	-4.4	-3.9	**-4.7**
15	Fond+$N_{75-120}P_{3.0}K_{60}$	-7.2	+3.3	-16.2	-0.6	-4.6	-5.0	**-5.1**
16	Fond+$N_{90-150}P_{3.0}K_{60}$	-5.6	+3.6	-14.9	-0.7	-3.0	-3.1	**-4.0**
17	Fond+$N_{30-120}P_{3.0}K_{120}$	-7.7	+5.4	-14.4	-1.1	-4.5	-5.8	**-4.7**
18	Fond+$N_{30-120}P_{3.0}K_{60}$+Zn_{10}	-6.8	+5.4	-16.9	+0.3	-4.5	-5.4	**-4.7**

Winter wheat. It was established that in the control variant, the 24-35 kg/ha of phosphorus is annually exported from the soil with winter wheat (Table 4).

Table 4. Phosphorus balance when growing winter wheat on leached chernozem, kg/ha

No.	Variant	Winter wheat (average by periods)						
		1991-1995	1996-2000	2001-2005	2006-2010	2011-2015	2016-2020	**1991-2020**
1	Control	-31.1	-24.2	-35.5	-33.0	-27.0	-26.8	-29.3
2	Fond*	-16.5	-10.1	-26.5	-17.3	-23.5	-23.2	-19.9
3	$N_{120}P_{1.0-1.5}K_{60}$	-13.3	+4.0	+6.9	-1.3	+9.9	+4.0	+2.2
4	$N_{120}P_{1.5}K_{60}$	-17.0	+1.1	+6.4	-4.6	+5.7	-4.8	-1.9
5	$N_{120}P_{2.0}K_{60}$	-19.0	-0.2	+4.1	-9.8	+1.9	-10.9	-5.5
6	$N_{120}P_{2.5}K_{60}$	-20.9	-1.8	+2.9	-13.9	-1.1	-14.9	-8.2
7	$N_{120}P_{3.0}K_{60}$	-21.2	-2.7	+1.0	-16.1	-2.8	-16.1	-9.6
8	$N_{120}P_{3.5}K_{60}$	-21.3	-3.3	-1.1	-17.4	-3.5	-16.2	-10.4
9	$N_{120}P_{4.0}K_{60}$	-21.4	-4.1	-1.2	-17.1	-2.9	-15.6	-10.3
10	$N_{120}P_{4.5}K_{60}$	-21.2	-4.3	-1.5	-16.9	-2.9	-16.4	-10.4
11	$P_{3.0}K_{60}$	-11.1	+4.4	+3.4	-6.4	+9.1	+4.0	+1.2
12	$N_{30}P_{3.0}K_{60}$	-19.6	+0.9	+2.8	-10.8	+2.9	-3.8	-4.2
13	$N_{60}P_{3.0}K_{60}$	-21.5	-2.1	-0.2	-15.2	-0.1	-11.2	-8.1
14	$N_{90}P_{3.0}K_{60}$	-21.1	-5.6	-0.5	-17.5	-3.4	-15.2	-10.4
15	$N_{120}P_{3.0}K_{60}$	-18.8	-7.6	+1.1	-17.3	-3.0	-16.1	-10.2
16	$N_{150}P_{3.0}K_{60}$	-17.0	-8.5	+3.1	-15.6	-1.3	-14.2	-8.8
17	$N_{120}P_{3.0}K_{120}$	-22.2	-4.1	-0.6	-16.6	-3.3	-17.1	-10.6
18	$N_{120}P_{3.0}K_{60}$ + Zn_{10}	-21.5	-4.3	+0.4	-15.5	-3.5	-19.7	-10.8

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

The average of phosphorus balance for 1991-2020 was 29.3 kg/ha. The phosphorus balance improvement was observed on the field with manure in dose of 60 t/ha. The application of organic and mineral fertilizers on the leached chernozem on average over 30 years led to a reduction in the negative balance by 18.5-31.5 kg/ha compared to the control variant. Phosphorus fertilizers in doses of 45 kg/ha did not fully compensate for this deficit with the obtained crops, the balance becoming equilibrated or positive only in the variants with lower yields. On average in crop rotation during the 1991-2020 on fertilized variants, phosphorus fertilizers led to a decrease in the negative P_2O_5 balance by 21 kg/ha compared to the control variant (Table 4).

Corn grains. As a research result, it was established that on the control variant, approximately 29-41 kg/ha of phosphorus is annually exported from the soil with corn, the average for 1991-2020 was 33.8 kg/ha. The application of organic and mineral fertilizers with phosphorus during the research years led to a decrease in the negative phosphorus balance by 18.9-43.7 kg/ha compared to the control variant. Phosphorus fertilizers in doses of 45 kg/ha practically compensated this deficit, the balance becoming equilibrated and even positive in some variants. On average over 30 years on the leached chernozem during corn cultivation, the negative phosphorus balance decreased by 29.6 kg/ha compared to the unfertilized variant (Table 5).

Table 5. Phosphorus balance when growing corn for grain on the leached chernozem, kg/ha

No.	Variant	Corn grains (average over periods)						
		1991-1995	1996-2000	2001-2005	2006-2010	2011-2015	2016-2020	**1991-2020**
1	Control	-33.9	-29.2	-31.7	-29.7	-40.8	-37.7	**-33.8**
2	Fond*	-22.8	-8.2	0	-38.1	-30.3	-26.6	**-21.0**
3	$N_{120}P_{1.0\text{-}1.5}K_{60}$	-2.5	+5.1	+13.0	+2.6	-7.0	-4.1	**+1.2**
4	$N_{120}P_{1.5}K_{60}$	-3.0	+2.8	+11.8	-0.9	-12.5	-6.9	**-1.5**
5	$N_{120}P_{2.0}K_{60}$	-8.2	+1.4	+11.2	-1.0	-15.3	-10.3	**-3.7**
6	$N_{120}P_{2.5}K_{60}$	-9.8	+0.3	+12.0	-0.8	-16.7	-11.8	**-4.5**
7	$N_{120}P_{3.0}K_{60}$	-12.0	+11.6	+11.5	-1.7	-16.0	-13.6	**-3.4**
8	$N_{120}P_{3.5}K_{60}$	-7.2	+0.5	+11.4	+0.1	-16.9	-13.9	**-4.3**
9	$N_{120}P_{4.0}K_{60}$	-12.9	-4.1	+11.9	+5.8	-16.3	-13.2	**-4.8**
10	$N_{120}P_{4.5}K_{60}$	-8.6	+0.5	+10.6	+5.9	-15.7	-13.6	**-3.5**
11	$P_{3.0}K_{60}$	-6.1	+3.2	+9.5	+0.2	-6.4	-2.4	**-0.3**
12	$N_{30}P_{3.0}K_{60}$	-11.3	+2.2	+10.3	-1.2	-11.8	-5.7	**-2.9**
13	$N_{60}P_{3.0}K_{60}$	-14.2	+0.8	+10.2	-1.9	-17.7	-11.2	**-5.7**
14	$N_{90}P_{3.0}K_{60}$	-12.9	+0.5	+11.1	-1.0	-16.8	-13.3	**-5.4**
15	$N_{120}P_{3.0}K_{60}$	-15.0	-0.4	+10.4	-1.9	-17.2	-14.1	**-6.4**
16	$N_{150}P_{3.0}K_{60}$	-12.7	+0.4	+10.0	-0.9	-15.7	-13.5	**-5.4**
17	$N_{120}P_{3.0}K_{120}$	-14.4	+1.0	+10.0	-0.7	-17.2	-14.0	**-5.9**
18	$N_{120}P_{3.0}K_{60}+Zn_{10}$	-14.2	+0.4	+10.5	0	-16.6	-13.8	**-5.6**

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

Sunflower. It was established that with the sunflower harvest on the control variant, approximately 17-35 kg/ha of phosphorus was exported from the soil annually, the average for the 1991-2020 being 26.3 kg/ha (Table 6). The application of mineral fertilizers with phosphorus in doses of 45 kg/ha largely compensated this deficit in the researched variants, the phosphorus balance being equilibrated and positive throughout the research period (Table 6).

Thus, we can consider that the dose of 45 kg/ha of P_2O_5 for sunflower can ensure a phosphorus balance in soil at the equilibrated state

Legumes *(peas, soybeans, beans).* Based on the research, it was established that in the unfertilized variant, approximately 14-25 kg/ha of phosphorus was annually exported from the soil with legumes, on average over the period 1991-2020, obtaining a negative balance -minus 20.6 kg/ha of phosphorus (Table 7).

Table 6. Phosphorus balance in sunflower cultivation on leached chernozem, kg/ha

No.	Variant	Sunflower (average over periods)						
		1991-1995	1996-2000	2001-2005	2006-2010	2011-2015	2016-2020	**1991-2020**
1	Control	-35.0	-17.1	-35.5	-17.3	-27.3	-25.3	**-26.3**
2	Fond*	-25.0	+6.9	-22.2	-12.8	-24.7	-16.2	**-15.7**
3	$N_{45}P_{1.0\text{-}1.5}K_{60}$	-4.2	+18.3	+5.5	+24.2	+11.8	+12.9	**+11.4**
4	$N_{45}P_{1.5}K_{60}$	-3.4	+14.6	+4.6	+22.8	+10.1	+5.2	**+9.0**
5	$N_{45}P_{2.0}K_{60}$	-6.4	+12.4	+2.2	+20.8	+7.4	-0.3	**+6.0**
6	$N_{45}P_{2.5}K_{60}$	-7.6	+12.9	+1.0	+18.8	+4.1	-3.4	**+4.3**
7	$N_{45}P_{3.0}K_{60}$	-8.8	+12.0	+0.6	+17.5	+2.2	-4.4	**+3.2**
8	$N_{45}P_{3.5}K_{60}$	-7.1	+13.6	+1.0	+16.6	+1.2	-4.1	**+3.5**
9	$N_{45}P_{4.0}K_{60}$	-9.3	+12.6	+0.3	+16.1	+1.6	-3.3	**+3.0**
10	$N_{45}P_{4.5}K_{60}$	-9.0	+13.0	+0.3	+15.5	+1.2	-4.2	**+2.8**
11	$P_{3.0}K_{60}$	-8.7	+16.5	+2.3	+20.3	+7.5	+9.2	**+7.9**
12	$N_{30}P_{3.0}K_{60}$	-12.0	+14.8	+1.5	+16.8	+4.7	+3.0	**+4.8**
13	$N_{45}P_{3.0}K_{60}$	-10.8	+13.1	+1.1	+17.3	+1.7	-3.3	**+3.2**
14	$N_{60}P_{3.0}K_{60}$	-9.7	+12.2	+0.3	+16.4	+1.0	-3.2	**+2.8**
15	$N_{75}P_{3.0}K_{60}$	-7.1	+13.3	0.0	+17.7	+1.4	-3.1	**+3.7**
16	$N_{90}P_{3.0}K_{60}$	-3.8	+13.4	-0.2	+16.6	+2.1	-1.8	**+4.4**
17	$N_{45}P_{3.0}K_{120}$	-11.7	+12.5	+1.0	+16.7	+1.0	-3.0	**+2.8**
18	$N_{45}P_{3.0}K_{60}+Zn_{10}$	-11.3	+12.9	-0.4	+17.3	+1.9	-2.3	**+3.0**

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

Table 7. Phosphorus balance when growing legumes on leached chernozem, kg/ha

No.	Variant	Legumes (average over periods)						
		1991-1995	1996-2000	2001-2005	2006-2010	2011-2015	2016-2020	**1991-2020**
1	Control	-13.9	-19.7	-25.3	-22.1	-	-22.1	**-20.6**
2	Fond*	-13.8	-5.7	-18.0	-8.8	-	-	**-11.6**
3	$N_{30}P_{1.0\text{-}1.5}K_{60}$	+31.4	+17.6	+14.4	+17.8	-	+21.8	**+20.6**
4	$N_{30}P_{1.5}K_{60}$	+31.2	+16.0	+12.3	+16.5	-	+14.5	**+18.1**
5	$N_{30}P_{2.0}K_{60}$	+31.2	+15.1	+11.9	+14.4	-	+11.0	**+16.7**
6	$N_{30}P_{2.5}K_{60}$	+31.2	+14.6	+5.2	+11.1	-	+10.1	**+14.4**
7	$N_{30}P_{3.0}K_{60}$	+28.1	+14.3	+7.9	+9.6	-	+9.3	**+13.8**
8	$N_{30}P_{3.5}K_{60}$	+28.8	+38.4	+9.0	+9.0	-	+11.4	**+19.3**
9	$N_{30}P_{4.0}K_{60}$	+28.7	+13.8	+7.8	+8.8	-	+11.9	**+14.2**
10	$N_{30}P_{4.5}K_{60}$	+28.8	+13.6	+8.9	+8.9	-	+12.9	**+14.6**
11	$P_{3.0}K_{60}$	+30.8	+15.1	+10.8	+13.7	-	+13.9	**+16.9**
12	$N_{30}P_{3.0}K_{60}$	+30.4	+13.8	+10.0	+10.5	-	+13.1	**+15.6**
13	$N_{45}P_{3.0}K_{60}$	+28.6	+12.9	+7.6	+8.3	-	+12.0	**+13.9**
14	$N_{60}P_{3.0}K_{60}$	+29.5	+12.7	+7.7	+8.9	-	+10.5	**+13.9**
15	$N_{75}P_{3.0}K_{60}$	+29.8	+11.5	+8.8	+10.2	-	+11.1	**+14.3**
16	$N_{90}P_{3.0}K_{60}$	+29.5	+12.1	+9.6	+10.8	-	+12.8	**+15.0**
17	$N_{30}P_{3.0}K_{120}$	+28.6	+12.1	+7.7	+8.5	-	+11.9	**+13.8**
18	$N_{30}P_{3.0}K_{60}+Zn_{10}$	+29.8	+13.0	+8.0	+9.1	-	+11.4	**+14.3**

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

The negative balance in the unfertilized variant was maintained throughout the entire period of legume cultivation. Organic and mineral fertilizers led to a decrease in the negative phosphorus balance on average from 9.0 kg to 41.2 kg/ha compared to the unfertilized variant. The application of mineral fertilizers with phosphorus in doses of 45 kg/ha compensated for the phosphorus deficit, the phosphorus balance being positive throughout the entire research period (Table 7).

Thus, we can consider that the dose of 40-45 kg/ha of P_2O_5 for leguminous crops for grains can ensure a equilibrated phosphorus balance.

Lucerne. As a result of the investigations, it was established that the phosphorus balance when growing alfalfa on leached chernozem during the period 1991-2010 largely depended at the

production level, which in turn was influenced by weather conditions and ranged from negative -72,8 kg/ha to positive +15,0 kg/ha. On the control variant, approximately 21-59 kg/ha of phosphorus was annually exported from the soil with the green mass harvest, the average was 36.1 kg/ha (Table 8).

On the variants with plant residues (Fond*) the phosphorus balance was negative by approximately 6-7 kg/ha, but higher yields were obtained compared to the unfertilized variant. The application of manure in the autumn of 2005 in dose of 60 t/ha (Fond*) increased the harvests level and reduced the negative phosphorus balance by 22 kg/ha compared to the control variant. On average, the negative phosphorus balance on leached chernozem, during the investigation period, on the fertilized variants reduced by 8-26 kg/ha compared to the control variant (Table 8). Therefore, the role of organo-mineral fertilizers in maintaining a equilibrated phosphorus balance is important in the alfalfa fertilization.

Table 8. Phosphorus balance when growing alfalfa on leached chernozem, kg/ha

No.	Variant	Lucerne (average over periods)						
		1991-1995	1996-2000	2001-2005	2006-2010	2011-2015	2016-2020	**1991-2020**
1	Control	-58.7	-21.2	-37.5	-27.0	-	-	**-36.1**
2	Fond*	-	-27.0	-44.8	-5.0	-	-	**-25.6**
3	$N_{60}P_{1.0\text{-}1.5}K_{60}$	-39.1	+15.0	-4.7	-11.0	-	-	**-10.0**
4	$N_{60}P_{1.5}K_{60}$	-51.8	+11.0	-9.0	-17.0	-	-	**-16.7**
5	$N_{60}P_{2.0}K_{60}$	-57.8	+9.6	-11.8	-20.7	-	-	**-20.2**
6	$N_{60}P_{2.5}K_{60}$	-60.9	+7.5	-17.6	-22.8	-	-	**-23.5**
7	$N_{60}P_{3.0}K_{60}$	-52.7	+6.7	-17.9	-24.1	-	-	**-22.0**
8	$N_{60}P_{3.5}K_{60}$	-64.2	+7.2	-18.9	-25.1	-	-	**-25.3**
9	$N_{60}P_{4.0}K_{60}$	-63.9	+7.2	-20.1	-24.8	-	-	**-25.4**
10	$N_{60}P_{4.5}K_{60}$	-63.7	+6.7	-20.4	-25.4	-	-	**-25.7**
11	$P_{3.0}K_{60}$	-47.3	+11.0	-13.3	-20.2	-	-	**-17.5**
12	$N_{30}P_{3.0}K_{60}$	-54.1	+8.0	-15.2	-22.9	-	-	**-21.1**
13	$N_{60}P_{3.0}K_{60}$	-63.1	+7.5	-19.9	-27.1	-	-	**-25.7**
14	$N_{90}P_{3.0}K_{60}$	-66.0	+6.1	-19.9	-25.4	-	-	**-26.3**
15	$N_{120}P_{3.0}K_{60}$	-72.5	+6.7	-20.7	-25.0	-	-	**-27.9**
16	$N_{150}P_{3.0}K_{60}$	-72.8	+7.5	-20.9	-23.1	-	-	**-27.3**
17	$N_{60}P_{3.0}K_{120}$	-63.8	+7.2	-16.8	-24.8	-	-	**-24.6**
18	$N_{60}P_{3.0}K_{60}$+Zn_{10}	-67.4	+6.7	-20.4	-26.4	-	-	**-26.9**

***Note**: Period 1991-1995: Fond - 0; Period 1996-2005: Fond - plant residues; Period 2006-2010: Fond - 60 t/ha manure + plant residues.

CONCLUSIONS

It was established that the phosphorus balance on the leached chernozem in the three fertilization systems during 1991-2020 period ranged from negative to positive. In the control variant the phosphorus balance was negative throughout the throughout period, with average minus 30.5 kg/ha.

The phosphorus fertilizers application in doses 45 kg/ha on the field with the mineral application system equilibrated the phosphorus balance, on average during 1991-2020 period, from minus 1.3 to -12.9 kg/ha annually.

On the fond of manure in dose of 60 t/ha associated with plant residues, phosphorus mineral fertilizers in doses 45 kg/ha led to an increase in field crop yields, while also reducing the negative phosphorus balance, on average over a 30-year period from -2.7 to -10.1 kg/ha annually.

The phosphorus balance on the organic-mineral system with mineral fertilizers application, phosphorus in doses of 45 kg/ha, on the background of plant residues, on average over the period 1991-2020, was eqiulibrated (-0.7… -5.1 kg/ha) and even positive (+0.4…+4.1 kg/ha), thus reducing the negative balance to a minimum.

At the cultivating the winter wheat, corn for grains, sunflower and leguminous crops on leached chernozem, the phosphorus fertilizers application in dose of 45 kg/ha compensated the phosphorus deficit, the balance becoming equilibrated or positive. For alfalfa, the compensation of the annual export of

phosphorus with green mass over 5 years of growing, the dose of 300-350 kg/ha P_2O_5 at the soil basic tillage before the sowing of the culture is sufficient.

Organic-mineral fertilizers led to an increase in the field crops productivity and a decrease in the negative phosphorus balance in the rotation, on average by 19.7-36.1 kg/ha compared to the control variant. The role of organic-mineral fertilizers in maintaining a equilibrated phosphorus balance is essential in the fertilization system of agricultural crops.

ACKNOWLEDGEMENTS

This research was carried out with the support of National Agency for Research and Development of the Republic Moldova, within the project No.20.80009.5107.25: Evaluation and optimization the nutrients and organic matter balance for improving the fertilization system of agricultural crops by making fertilizer use more efficient and increasing soil fertility in sustainable agriculture (2020-2025).

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