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THE BALANCE OF HUMUS AND NUTRIENTS OF CROP ROTATION WITH THE APPLICATION OF PLANT RESIDUES AND FERTILIZERS IN SMALL DOSES ON CALCAREOUS CHERNOZEM OF MOLDOVA

Diana Indoitu [1*]

[1]Agricultural State University of Moldova, Mircheshti Street, no. 42, Chisinau, Republic of Moldova

Abstract
The balance of soil fertility in the current conditions of agriculture has a topical interest. The basic objectives of the research were to assess the possibility of obtaining a non-deficit balance of the main indicators of soil fertility (humus, nutrients) in Calcareous Chernozem using small doses of mineral fertilizers and the return of plant residues of cultivated crops. The mass balance that comprises inputs and outputs for humus, nitrogen (N), phosphorus (P) and potassium (K) from cropland of the cereal crop rotation in the 2001-2017 period in the long-term experience was analyzed. We found a deficit in N (-1.2 kg.ha^{-1} .yr$^{-1)}$ using of crop residues on experimental plot without fertilization (since 1950) and a positive balance for P and K (5.7 and 43.8 kg.ha^{-1}.yr^{-1}). The combined use of plant residues and mineral fertilizers in small doses ($N_{47}P_{46}$) on previously fertilized backgrounds helps maintain the positive humus and N-P-K nutrient balance.

Keywords: balance, Chernozem, crop residues, humus, N-P-K nutrients.

1. INTRODUCTION

The current severe depletion of land resources around the world against the background of the growing demand for food makes the most urgent problem of their rational use. Soil is the main mean of production in agriculture, and the crop yield depends on the level of its fertility. Interference in the relatively closed cycle of biogenic elements existing in natural biocenoses violates the natural balance. The removal of nutrients by the crops requires their return to the soil. Therefore, the regulation of the balance of the most important indicators of soil fertility, humus and available nutrients, is of particular interest. Humus, which is a source of nutrients for plants, improves the physical and chemical properties of soil, activates soil biota, and so can be considered an indicator of soil fertility.

In the 1980s, with the widespread use of high doses of fertilizers, the balance of assimilable nutrients in the chernozems of Moldova was positive (+16+35 kg.ha^{-1}) and slightly negative in humus content (-0.4 t.ha^{-1}). By 2000, the balance was sharply negative and amounted to -36-150 kg.ha^{-1} and -1.1 t.ha^{-1}, respectively (Zagorcea, 1998; Andrieş and Zagorcea, 2002; Krupenikov and Boincean, 2004; Andrieş, 2007; Krupenikov, 2008). Scientists S. Andrieş and C. Zagorcea in 2002 made a disappointing forecast for further reduction of humus content to 2.5-3.0% by 2025 compared to 5-6% in 1897.

*Corresponding author, E-mail address: ind.diana@hotmail.com

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As excessive accumulation of water-soluble nutrients in the soil, followed by their migration along the profile, leads to disruption of the optimal balance of biophilic elements, and the lack of mobile forms of nitrogen, and partly of phosphorus, both reduce soil fertility and crop yields, grain quality deterioration, especially for winter wheat.

Only nitrogen fertilizers and, to a lesser extent, improving crop rotation are able to compensate for annual nitrogen losses (Krupenikov, 2008). Researches of Andrieş (2007, 2011), Donos (2008) devoted their papers to the nutrient regime of the soil in Moldova, in particular nitrogenous. According to generalized research data in the USA and Russia, the use of high doses of manure and the return to the soil of significant amounts of straw for 30-50 years can restore humus in the entire profile (Glazovskaya, 2003).

The high cost of mineral fertilizers, the inability to apply manure in necessary quantities throughout the territory due to the complexity of harvesting organic fertilizers, the lack of livestock farms or their uneven distribution, require the search for alternative sources of nutrients and organic matter to make up for their balance in the soil. One of the most affordable, environmentally friendly and cheap source of organic matter in agriculture is plant residues. They play an important role in the biological cycle of substances and for maintaining soil fertility. According to the data of various studies, plant residues can be variable in their quantity and content, C/N ratio, mineralization rate, which depends on many factors: biological characteristics, growing conditions, cultivation technology, etc. (Zagorcea, 1990; Gaillard et al., 1999; Trinsoutrot et al., 2000; Nicolardot et al., 2001; Abiven et al., 2005; Jensen et al., 2005; Clay et al., 2017). Therefore, it is very important to assess the balance of nutrients and humus in the crop rotation over a long period.

Balance is determined by the total number of elements that entered the system soil - fertilizer - plant, and were taken out of it (Peterburgskii, 1983). The balance of humus consists of the amount of incoming organic matter and the consumption of humus for a certain period of time or in a certain area. The income side of biophilic elements balance includes substances with fertilizers and ameliorants, root and stubble residues, sediments, seeds, nitrogen fixation, etc. The outcome side includes removal of nutrients with yield, migration of substances beyond the root layer, evaporation from the soil and transpiration of plants, denitrification, soil loss with water and wind erosion, etc. If the balance is positive, the income exceeds the outcome, the loss is compensated. Back in 1937 the Russian agrochemist D.N. Pryanishnikov, who studied the problem of the cycle and balance of substances in agriculture, came to the conclusion that it was necessary to achieve nitrogen reimbursement by 80%, phosphorus - by 100-110% (Prianishnikov, 1965). It is important not to forget that the assimilation of one element depends on the content of other nutrients.

2. MATERIALS AND METHODS

The basic objective of the research was to assess the possibility of obtaining a non-deficit balance of the main indicators of soil fertility (humus and nutrients) in Calcareous chernozem[1] of Moldova using small doses of mineral fertilizers and the return of all plant residues of cultivated crops.

The research was carried out in the long-term field experiment with fertilizers (from 1950) on the Chetrosu Experimental Station of the State Agrarian University of Moldova. The station is situated in the Central Zone of Moldova (Chetrosu, Anenii Noi). Studies were conducted in the 2001-2017 period.

The Central Zone of Moldova experiences a continental climate with rainfalls varying between 246 and 550 mm and an annual mean of 449 mm. As a rule, drought occurs 1 year every three or four.

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The soil is Calcareous chernozem: light loam with 2.5-3.0% humus (Tyurin), 0.8-1.5 mg.100g^{-1} mobile phosphate (Machigin), 18-22 mg.100g^{-1} exchangeable potassium and 1.8-2.2% carbonates in the 0-20 cm layer.

The experimental crop rotation is eight-field: maize for grain (M.) – peas (P.) – winter wheat (W.W.) – winter wheat (W.W.) – maize for grain (M.) – peas (P.) – winter wheat (W.W.) – sunflower (S.) (in 2003, another wheat was introduced before sunflower into the crop rotation). This rotation was put in place after two complete cycles of ten-field crop rotation with low doses of fertilizer (1950–1970). Since 1971, a system of fertilization for the planned yield was used in the eight-field crop rotation: annual applications of mineral fertilizers 300 kg NPK/ha – $N_{120}P_{90}K_{90}$ (from 1999 $N_{90}P_{60}K_{60}$); an equivalent annual application of farmyard manure at 24 t.ha^{-1} (from 1999 18 t.ha^{-1}); combined manure at 12 t.ha^{-1} + mineral $N_{60}P_{60}K_{45}$ (from 1999 manure 9 t.ha^{-1} + mineral $N_{45}P_{45}K_{30}$). Since 2005, the aftereffect of fertilizers has been studied. Since 2008, the minimum doses required of mineral fertilizers $N_{47}P_{46}$ have been introduced.

In this study, we examine the balance of humus and nutrients of crop rotation with the application of all plant residues (stalks, stubble, roots) and fertilizers in small doses on four experimental plots: without fertilization from 1950 (I), with influence of small doses of mineral fertilizers (on average $N_{47}P_{46}$ per year) on variants with previous long-term application of mineral ($N_{90}P_{60}K_{60}$) (II), organic – manure 18 t.ha^{-1} (III) and organomineral (manure 9 t.ha^{-1} + $N_{45}P_{45}K_{30}$) (IV) fertilizers.

The crop rotation is set up in three 2 ha fields, the area of each experimental plot is 200 m^2 (20 × 10 m), 3 replicates.

The vegetable residues were crushed during harvesting by the combine harvester and embedded in the soil: for winter wheat, during surface primary processing with disk implements, for corn, sunflower by plowing to a depth of 25-27 cm.

The humus balance (equation 1) is the difference between the quantity of humus formed from plant residues (using the humidification coefficient for each different culture) and the mineralized humus from the cropland under various crops (the data of studies on the chernozem of Moldova, Andrieş, 2007).

$$\text{The Balance of humus} = \sum \text{Neoformed humus} - \sum \text{Mineralized humus, t.ha}^{-1}.\text{yr}^{-1} \quad (1)$$

The mass balance for nitrogen, phosphorus and potassium (equation 2) of the crop rotation comprised inputs with mineral fertilizers, crop residues and outputs with grain yield.

The calculation of nitrogen balance did not take into account the receipt of seeds, sediments and losses due to denitrification, considering them to be approximately equal and compensating each other.

$$\text{The Balance of Nutrients (N/P/K)} = \sum \text{Input (N/P/K)} - \sum \text{Output (N/P/K), kg.ha}^{-1}.\text{yr}^{-1} \quad (2)$$

The balance of humus and nutrients was obtained for each culture in the study period, and then the average for the entire period was calculated.

3. RESULTS AND DISCUSSIONS

Chernozems have a fairly high potential fertility, which positively affects the productivity of crop rotation. On carbonate chernozem, in favorable weather conditions, it is possible to obtain a winter wheat crop at 2.8 t.ha^{-1} using only the natural fertility of the soil (Andrieş, 2007). In our experience on a plot with natural fertility (control without fertilizers since 1950) with the use of plant residues, the yield of winter wheat in favorable years reached 3.55 t.ha^{-1} (2016). In variants with the aftereffect of long-term use in the past for four rotations and small doses of fertilizers in the present

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(on average annually $N_{47}P_{46}$), the yield of winter wheat reached 6.00 $t.ha^{-1}$ (2016). Still, the limiting factor, which determines the productivity of crops grown in Moldova, has been and remains atmospheric precipitation. For example, for cultivation of winter wheat for the studied 17 years, the unfavorable were 2003, 2007, 2009, 2012, and 2003 was extremely unfavorable (with a yield of 0.16-0.33 $t.ha^{-1}$), which significantly affected the productivity of crop rotation as a whole. Figure 1 shows the average yield for three years (in three fields) of grain crops grown for the period 2001-2017.

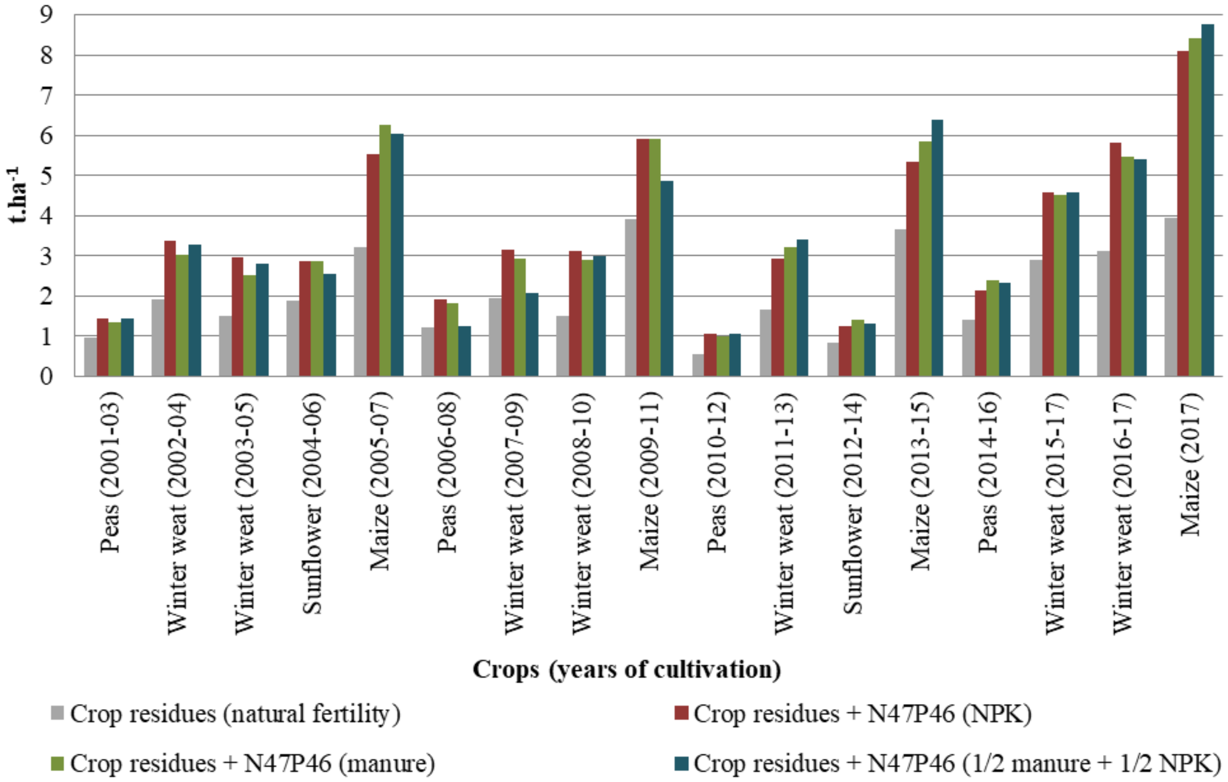

Figure 1. Average grain yield in the 2001-2017 period

The productivity of crop rotation and its effect on soil fertility is assessed not only by the grain yield, but also by biomass that is removed with the crop and introduced into the soil in the form of plant residues, as well as by the content of nutrients in these plant residues, which accordingly return to the soil. Figure 2 shows the yield of straw, root (in the 0-60 cm layer) and stubble residues in the 2001-2017 period.

In those 17 years, in this field crop rotation on plot with natural fertility, 47.0 $t.ha^{-1}$ of root and stubble residues and 62.2 $t.ha^{-1}$ of straw (total - 109.2 $t.ha^{-1}$) have formed, or respectively 2.76 and 3.66 (6.42 $t.ha^{-1}$) as average per year; on fertilized variants, respectively 58.1-58.6 and 104.1-105.9 (total 162.2-164.6 $t.ha^{-1}$), the average per year - 3,42-3,45 and 6,12-6,23 (9,54-9,68 $t.ha^{-1}$) .

On the fertilized plots, not only the grain yield increases, but also the amount of plant residues that get to the soil and pass into humus.

The balance of humus in crop rotation while introducing into the soil all plant residues (root and stubble residues, straw) for the 2001-2017 period was calculated in two ways: 1. the balance method using the humification coefficient and the amount of mineralized humus in the chernozem

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of Moldova under different crops (Andrieş, 2007); 2. nitrogen balance by the method of A.M. Lykov. Table 1 shows the balance by the first method.

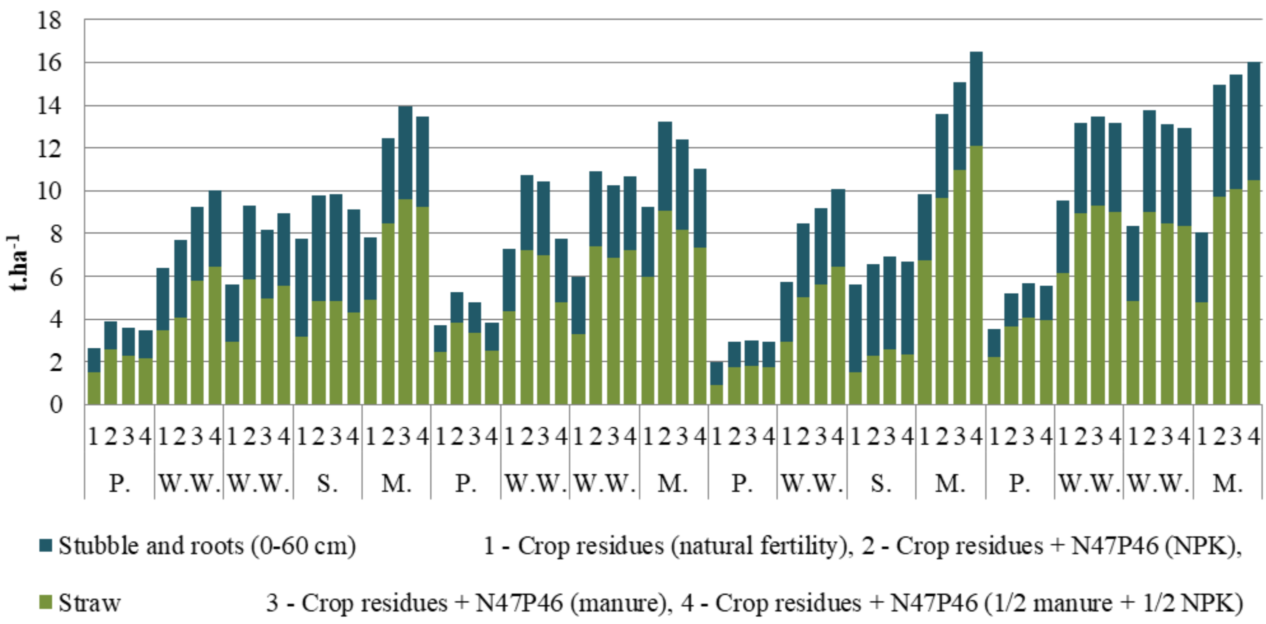

Figure 2. Average crop residues yield in the period 2001-2017

Table 1. Humus balance (average for the period 2001-2017), t.ha^{-1}.yr^{-1}

Component of humus balance	**Crop residues**			
	Without fertilization	**On average $N_{47}P_{46}$ per year**		
		Previous long-term application		
		NPK	**Manure**	**½ Manure + ½ NPK**
Neoformed from crop residues	1.20	1.78	1.81	1.79
Mineralization	1.09	1.09	1.09	1.09
Balance	0.11	0.70	0.72	0.70

According to studies, the amount of mineralized humus in Moldovan chernozem under different crops annually is comprised between 0.60 and 1.56 t.ha^{-1}. Of course, the mineralization of humus on fertilized plots proceeds more slowly than without fertilizers, but since in our experience organic fertilizers are not introduced in the form of manure, and the doses of mineral fertilizers are not large, we supposed the amount of mineralized humus was the same on all the plots, 1.09 t.ha^{-1}.yr^{-1} on average for the studied period. The humus balance is insignificantly positive in all variants, even without taking into account the amount of organic matter formed from the plant roots that died out during the growing season, without taking into account the root secretions, although according to different data this amount of dead roots may be 20% of the living weight, and root secretions may be 10% (Novikov et al., 2012). For the natural fertility of carbonate chernozem +0.11 t.ha^{-1}.yr^{-1} humus, this is not essential. On fertilized plots with the introduction of all plant residues according

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to the balance calculated with the first method, 0.70-0.72 t.ha^{-1}.yr^{-1} are formed, which is also not so much. Calculated by the method of A.M. Lykov the balance of humus was even more positive: on a plot with natural fertility, when introducing all plant residues into the soil, 0.47 t.ha^{-1} of humus is formed annually. A more positive balance of humus in the soil on fertilized plots is explained by the fact that mineral fertilizers, increasing the yield of cultivated crops, increase the amount of plant remains left in the soil.

The N-P-K soil nutrient balance is presented in table 2. On the average, in the crop rotation, 15.8 kg.ha^{-1} of nitrogen was supplied to the soil for a year with straw on a plot with natural fertility and 36.2 kg.ha^{-1} on fertilized plots; phosphorus, respectively, 7.0 and 17.5 kg.ha^{-1}; potassium 28.8 and 56.0 kg.ha^{-1}. 27.8 and 37.1 kg.ha^{-1} of N, 11.2 and 12.2 kg.ha^{-1} of P, 28.6 and 36.2 kg.ha^{-1} of K were introduced with root and stubble residues.

Table 2. The N-P-K balance (average for the period 2001-2017)

Plot	Input, kg.ha^{-1}.yr^{-1}				Output with yield, kg.ha^{-1}.yr^{-1}	Balance, kg.ha^{-1}.yr^{-1}	Intensity of balance, %	Capacity balance, kg.ha^{-1}.yr^{-1}
	With fertilizers	With straw	With stubble, roots	Total				
Nitrogen								
Crop residues (I)	0	15.8	27.8	43.6	44.8	-1.2	107.2	88.4
Crop residues + N47P46 (II)	46.9	35.5	37.1	97.9	83.4	14.5	125.2	181.2
Crop residues + N47P46 (III)	46.9	33.1	37.1	95.5	80.8	14.8	118.3	176.3
Crop residues + N47P46 (IV)	46.9	36.2	37.0	98.5	80.3	18.2	122.7	178.7
Phosphorus								
Crop residues (I)	0	7.0	11.2	18.2	12.5	5.7	151.0	30.7
Crop residues + N47P46 (II)	45.9	17.5	12.2	54.2	32.0	22.2	180.4	86.2
Crop residues + N47P46 (III)	45.9	17.2	12.2	53.9	34.0	19.9	158.5	88.0
Crop residues + N47P46 (IV)	45.9	16.6	12.2	53.2	33.6	19.6	158.2	86.9
Potassium								
Crop residues (I)	0	28.8	28.6	57.4	13.5	43.8	459.3	70.9
Crop residues + N47P46 (II)	0	55.4	36.1	91.5	25.3	66.2	392.7	116.8
Crop residues + N47P46 (III)	0	56.0	36.2	92.2	26.1	66.1	353.6	118.3
Crop residues + N47P46 (IV)	0	54.2	35.8	90.0	25.3	64.8	356.4	115.3

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The negative balance was only in the nitrogen without the usage of fertilizers. We found a deficit in N (-1.2 $kg.ha^{-1}.yr^{-1}$) with crop residues on experimental plot without fertilization (since 1950), on fertilized plots positive +14.5+18.2 $kg.ha^{-1}.yr^{-1}$. When straw is applied to the soil, it is recommended to apply an additional 3-11 kg of nitrogen with mineral fertilizers. This reduces the ratio of nitrogen and carbon in the soil and prevents the use of nitrogen from soil stocks by microorganisms for the decomposition of straw, which will worsen the nitrogen regime of plant nutrition in the initial period of development. But after a while, when a half the mass of the straw is decomposed, the amount of nitrogen increases. In our studies, on an average per year, it is necessary to bring 6.4 kg of nitrogen for 1 t of straw. On a plot with natural fertility, when introducing plant residues, the plants will experience an even greater nitrogen deficit, and on fertilized plots (N_{47}), the balance will still be positive.
The phosphorus and potassium balances were both positive, with phosphorus to a lesser degree (table 2). On experimental plot without fertilization 5.7 $kg.ha^{-1}.yr^{-1}$ for P and 22.2 $kg.ha^{-1}.yr^{-1}$ for K, on fertilized variants, respectively, 43.8, and 64.8 $kg.ha^{-1}.yr^{-1}$. The intensity of phosphorus balance was 151-180%. Sunflower leaves behind very potassium-rich plant residues in the crop rotation. In our studies this content was 99-144 $kg.ha^{-1}.yr^{-1}$. This explains the absence of need to introduce potash fertilizers with plant remains, in features on carbonate chernozem, which is sufficiently provided by this element.
The conducted studies show that if there is no possibility of using manure, which is known to have a very favorable effect on the fertility of the soil, it is possible to fill the plants' need for basic nutrients and maintain a positive balance of humus by introducing into the soil all plant residues of crops grown in the field crop rotation with additional application of nitrogen-phosphorus mineral fertilizers.

4. CONCLUSIONS

On average, depending on the soil fertility level and year conditions, it is possible to return 6.42-9.68 $t.ha^{-1}$ of plant residues to the carbonate chernozem with the field crop rotation, of which 35-43% or 2.76-3.45 $t.ha^{-1}$ made of root and stubble residues, and 57-64% or 3.66-6.23 $t.ha^{-1}$ of straw.
The introduced amount of plant residues provides the formation of 1.20 $t.ha^{-1}$ of humus on a plot with natural fertility and 1.78-1.81 $t.ha^{-1}$ on fertilized plots. Taking into account the mineralization, the humus balance is +0.11 $t.ha^{-1}$ and + 0.70-0.72 $t.ha^{-1}$, respectively. On fertilized plots, the balance of humus is higher due to an increase in yield and, consequently, an increase in plant residues left in the soil.
With plant residues, the soil receives from 43.6 to 98.5 $kg.ha^{-1}$ of nitrogen, from 18.2 to 53.9 $kg.ha^{-1}$ of phosphorus and from 57.4 to 92.2 $kg.ha^{-1}$ of potassium, which replenishes nutrients the yield of the main crop production in nitrogen by 87-97%, phosphorus by 86-146% and potassium by 353-425%. This explains the necessity to add a small dose $N_{47}P_{46}$ of mineral fertilizers to the plant residues.
The return to carbonate black earth all plant residues with the additional application of nitrogen-phosphorus fertilizers ($N_{47}P_{46}$) provides the need in nitrogen for microorganisms during the decomposition of plant residues, helps maintain a positive balance of humus and replenish the need for plants in nutrients.

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*Corresponding author, E-mail address: ind.diana@hotmail.com