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The ways of restoring the soils in Moldova

Načini obnove zemljišta u Moldaviji

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Abstract: Soil is the main natural resource of Moldova. The use of land resources provides 33-40% of the gross product of this country. Therefore, the qualitative state of soils largely determines the sustainable development of the Republic of Moldova. During the Soviet period, successful experiments were carried out in Moldova on the restoration of eroded soils by applying a layer of natural soil materials (meliorants) 30-45 cm thick to the surface of the eroded soil. The restored soils proved to be stable, and the yield of agricultural crops on the restored soils increased by 2 times. A significant part of the soil washed off the slopes is deposited on the bottom of streams and reservoirs. The effectiveness of soil restoration depends on the quality of the raw materials used for reclamation. Therefore, it is necessary to know the amount of chemical elements available to plants, which is contained in the raw material. The analysis carried out by the authors showed that the chemical composition of bottom sediments has been little studied.
The authors summarized the available data on the content of microelements in bottom sediments in the territory of Moldova, as well as conducted additional studies.

Keywords: soil, erosion, Moldova, bottom sediments, reclamation, microelements.

Sažetak: Zemljište je glavni prirodni resurs Moldavije. Korišćenje zemljišnih resursa obezbeđuje 33-40% bruto društvenog proizvoda ove zemlje. Dakle, kvalitativno stanje zemljišta u velikoj meri određuje održivi razvoj Republike Moldavije. Tokom sovjetskog perioda, u Moldaviji su sprovedeni uspešni eksperimenti na obnavljanju erodiranog zemljišta nanošenjem sloja prirodnih zemljišnih materijala (melioransa) debljine 30-45 cm na površinu erodiranog zemljišta. Obnovljena zemljišta su se pokazala kao stabilna, a prinos poljoprivrednih kultura na obnovljenim zemljištima povećan je za 2 puta. Značajan deo zemljišta ispranog sa padina odlaže se na dno potoka i rezervoara. Efikasnost sanacije zemljišta zavisi od kvaliteta materijala koji se koriste za rekultivaciju. Zbog toga je neophodno znati količinu hemijskih elemenata dostupnih biljkama, koja je sadržana u njima. Analiza koju su izvršili autori pokazala je da je hemijski sastav donjih sedimenata malo proučavan. Autori su sumirali dostupne podatke o sadržaju mikroelemenata u donskim sedimentima na teritoriji Moldavije, kao i sproveli dodatne studije.

Ključne reči: zemljište, erozija, Moldavija, donji sedimenti, melioracija, mikroelementi.

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INTRODUCTION

The main environmental problems at the end of the Soviet period of Moldova's development were related with chemical contamination of soils, soil erosion, depletion and water pollution (Kochurov, 2003). These problems are relevant today, but there was a change in their priorities. Soil degradation, especially caused by erosion, has come to the fore. Concerning the abrupt reduction in the use of mineral fertilizers and plant protection products, soil pollution has given way of their depletion (Kapitalchuk, 2021).

Soil is the main natural resource of Moldova. The use of land resources provides 33-40% of the gross product of this country. Therefore, the qualitative state of soils largely determines the sustainable development of the Republic of Moldova. However, this important natural resource is being degraded. The main factor of soil degradation here is erosion, which has covered 70% of agricultural land. The total damage from erosion in Moldova is estimated at 230 million US dollars (Leah, 2012, 2013). For the economy of such a small country, the damage from erosion is very significant.

The problem of soil degradation in Moldova and its solutions have been studying by many scientists for several decades. The results of these studies are presented in dozens of articles and several monographs. To solve this problem, a national program for the development of degraded lands and increasing soil fertility (Program, 2005) was developed, which was not implemented due to unfavorable economic factors. However, the area of eroded lands is increasing at a rate of 0.30–0.45% per year (Leah, 2013). Therefore, the problem of soil degradation in Moldova not only remains relevant, but continues to grow. For the sustainable development of the country, it is necessary to carry out land reclamation. In this regard, the purpose of this article is to assess the current state of the problem of soil degradation in Moldova and to find methods to solve this problem.

1. MATERIALS AND METHODS

The authors of this article analyzed and summarized information about the problem of soil degradation in Moldova, which is contained in available publications. Also supplemented this information with data on the chemical composition of soils and sediments, the dynamics of the use of mineral fertilizers on agricultural land, and the effect of fertilizers on soil productivity. The method of selection of soil samples is described in the article (Kapitalchuk et al., 2014), and the method of selection of sediments is presented in the article (Kapitalchuk et al., 2015). The concentration of chemical elements in the samples was determined using a Perkin Elmer atomic absorption spectrophotometer Aanalyst800. The contenting of selenium in the samples was determined by the microfluorometric method. Data of using of fertilizers and crop yields are provided by the relevant agricultural organizations.

The chemical load factor was used to assess the effect of chemicals introduced into the soil on the productivity of the soil. This indicator is the ratio of the amount of chemical that entered the agroecosystem per year to the area of this agroecosystem. The sum of the partial coefficients for different chemicals is an indicator of the total chemical load (Ch_{total}) on the agroecosystem (Kapitalchuk, Doga, 2003; Kapitalchuk, 2021).

To assess the productivity of the soil, a dimensionless coefficient is applied – "normalized yield", which is represented as:

$$k_i = \frac{C_i}{\bar{C}}, \quad (1)$$

where C_i is the yield of the *i*-th agricultural crop for a particular year, $\bar{C}$ is the average yield of the *i*-th agricultural crop for the period under consideration.

This dimensionless indicator allows you to compare the productivity of the soil for an agricultural crop for a particular year with its average yield in the agroecosystem for the period under review. In addition, this coefficient makes it possible to calculate the integral yield as the arithmetic mean of normalized yields for several crops:

$$k_O = \frac{\sum k_i}{n}, \quad (2)$$

where k_i is the normalized yield of the *i*-th agricultural crop, n is the number of crops under consideration (Kapitalchuk, 2021).

2. RESULTS AND DISCUSSION

2.1. Causes and consequences of soil degradation

Intensification of agricultural production in Moldova in the 1970 and 1980 was carried out on the basis of extensive use of chemicalization, water reclamation, mechanization with the use of heavy machinery. These man-made methods of farming have led to the intensification of soil degradation.

The problem of soil degradation in Moldova is considered in detail by I.A. Krupenikov (2008), who systematized and described 40 types of degradation of chernozems, combined into 5 types: 1) chemical, 2) physical, 3) biological, 4) profile, 5) geographical and biospheric degradation.

Chemical degradation of the soil manifests itself in the form of a negative balance of humus, nitrogen, phosphorus, potassium and other plant nutrients. Deficiency of some biogenic elements may also occur in the soil due to their removal by water runoff and removal from the agroecosystem together with the crop yield. Man-made pollution, on the contrary, causes an excess of some elements in the soil. Violation of irrigation norms leads to excessive salinization of soils. To the chemical type of degradation of I.A. Krupenikov (2008) also attributed contamination of soils with radionuclides during atomic emissions, but this type of degradation has not been recorded in Moldova.

The main cause of chemical degradation of soils is the excessive use of mineral fertilizers and plant protection products. In terms of costs, chemicalization in Moldova was second only to water land reclamation. Excessive use of chemicals in agriculture caused not only soil degradation, but also caused pollution of water bodies, eutrophication of reservoirs, deterioration of sanitary living conditions of the population and living conditions of organisms in soil and aquatic ecosystems.

Several stages can be distinguished in the dynamics of chemical effects on agricultural lands of Moldova (Kapitalchuk, Doga, 2003): 1) 1974-1982 – a period of growth; 2) 1983-1990 – a period of stabilization at a high level; 3) 1991-1994 – a period of decline; 4) from 1995 to the present – a period of stabilization at a low level.

As an example, we will give the indicators of the total chemical load on agricultural lands of the Kamensky administrative district. During 1974-1982, the indicator of the total chemical load (Ch_{total}) increased from 29 to 68 kg/ha. During 1983-1990, the chemical load indicators varied, remaining at a high level: Ch_{total} = 62-81.6 kg/ha. In the period 1990-1994, the total chemical load decreased to 15.4 kg/ha. After 1995, the total chemical load was less than 3 kg/ha. The fast reduction in the use of fertilizers led to soil depletion, which manifested itself in the form of a decrease in crop yields by the mid-1990.

For more detailed studying of the effect of fertilizers on soil productivity, retrospective studies were conducted on the lands of the agricultural enterprise "Giska", which is located near the city of Bendery. The materials for the analysis were various forms of reports of this enterprise, which contained information on crop yields and fertilization from 1966 to 2007 on an area of 1400 hectares. Only the lands allocated for arable land were considered, so the chemical load for them turned out to be an order of magnitude higher than for administrative districts. Calculating the integral yield, the yields for the corresponding years of wheat, corn and sunflower were used. These crops occupied the main share of arable land in the studied territory.

The dynamics of fertilizer application had the following features. During 1966-1976, an average of 100 to 300 kg/ha of mineral fertilizers were applied. Next period from 1977 to 1984, the amount of fertilizers applied increases to 600-700 or more kg/ha. However, in 1985 the use of fertilizers decreased to the level of 1975, in 1991 their use decreased to the level of 1966, and in 1994 it almost reached zero.

There are no such significant changes in the dynamics of the integral yield, but in the time course of this indicator there is a number of characteristic periods that can be associated with the dynamics of fertilization. So in 1966-1976, there are fluctuations in the integral yield within 20% relative to the average yield for the entire time interval under consideration.

Intensive application of fertilizers in subsequent years led to stabilization of the integral yield at a higher level with an excess of the average yield of about 40%. Some years, this excess reaches 60-70%. Against the background of a decrease in the intensity of fertilizer use after 1984, the integral yield continued to remain at a high level until 1990. That is, the "reaction" of the integral yield to a decrease in the amount of fertilizers was manifested with a delay of about five years. This fact confirms the result obtained earlier for administrative districts.

Since 1991, instability has been manifested in the nature of the time course of the integral yield, expressed in the form of fluctuations in the range of values of 40-50% relative to the average for the entire period. Last time interval of 1998-2007 is characterized by the values of the integral yield below the average for the entire period with a tendency to further decrease. Thus the decrease in the use of fertilizers led to the depletion of soils.

However mineral fertilizers is not the only factor affecting the yield of agricultural crops. The correlation coefficient between the integral yield and the amount of fertilizers applied was only 0.59 with a significant level of 0.01. It also should be taken into account that the sensitivity of different crops to the amount of fertilizers applied varies. Indeed the value of the correlation coefficient between the parameters under consideration at a significance level of 0.01 is only 0.36 for winter wheat, 0.64 for corn.

The weather conditions have significantly affect in yield of agricultural crops also the other factors. However, this influence manifests itself mainly in the form of fluctuations in annual values of the integral yield. At the same time, the nature of the trend line, leveling these deviations, will be mainly due to the property of the soil and, therefore, will characterize its productivity.

The peculiarity of the geochemical conditions of Moldova is that the soils of this country are characterized by an optimal content and ratio of many trace elements. Therefore for a number of trace elements (B, Mn, Cr, Cu, F, I, Mo, Ni, Zn), low availability of soils with their mobile forms are locally noted (Kapitalchuk, Kapitalchuk, 2020). The lack of trace elements in the soil can cause various pathologies of plants and animals.

Types of chemical degradation decalcification and acidification of soils are not peculiar to the soils in Moldova, since calcium accounts for 85-90% in the composition of exchange cations in them, and the saturation of bases in a layer of 0-40 cm in carbonate chernozems is 100% in typical chernozems – 91-96% (Krupennikov, 2008). These types of degradation can be limited only in the northern part of the country, where carbonates lie at a considerable depth.

The main reason of physical degradation of soils is their prolonged processing, which led to a violation of the granulometric composition and over–compaction of soils. This cause the degradation of the arable layer, violation of the water regime and an increase in surface runoff, the gas exchange suppression and other physical functions of soils. In Republic of Moldova, the over-compaction of arable soils are observed on an area of 1782 thousand hectares, which entails an annual damage of 385 million lei (Krupenikov, 2008).

In Moldova the formation of local foci of excessive moisture is common when the groundwater level rises or they exit to the surface of the slope. I.A. Krupenikov (2008) defined this phenomenon as a type of physical degradation of the soil. However, this phenomenon, as a rule, has a natural process. Therefore, it is possible to consider these foci as the cause of soil degradation only conditionally due to the impossibility of their use for agricultural production. Their reclamation is an expensive undertaking, and economically inefficient. It is advisable to use waterlogged foci as elements of the ecological framework.

Biological degradation of soils manifests itself in the form of oppression, suppression and reduction of the number of shrews, mesofauna and microorganisms. This type of degradation is closely related to chemical and physical degradation, as it is a direct consequence of dehumification and salinization of soils, over-compaction and destruction of soil structure. It turned to be, the depressed state of the soil biota reduces the ability of the soil to perform its functions.

Profile degradation is the most dangerous, since it leads to the destruction of the genetic horizons of the soil and enhances all other types of degradation. The main causes of profile degradation are the hydromechanical washing of soil from slopes, destruction of soils by ravines and landslides.

The main factor of profile land degradation is erosion, which is developing at an accelerating pace. 26 million tons of fertile soil, 700 thousand tons of humus, 50 thousand tons of nitrogen, 34 thousand tons of phosphorus, 597 thousand tons of potassium annually are washed away from eroded lands. Soil flushing leads to the redistribution of chemical elements along the slope and along the vertical profile of the soil. The forms of chemical compounds of elements and their availability for assimilation by plants are changing (Leah, 2012, 2013).

Linear erosion is also widespread through the territory of Moldova, which leads to the formation of ravines. The area of land covered by ravines exceeds 10 thousand hectares (Soil erosion, 2001).

Another unfavorable phenomenon for soils is landslides, which destroy the soil cover and destroy the landscape as a whole, as well as pose a danger to man-made infrastructure and directly to the population. Currently, there are 16 thousand modern active landslides covering 2.4% of the territory of Moldova (Krupenikov, 2008; Soil erosion, 2001).

The geographical and biospheric type of soil degradation was identified by I.A. Krupenikov (2008) due to the fact that soil degradation has acquired a global character. The variety of soil-forming factors caused the heterogeneity of the soil cover, which was supplemented by differentiated anthropogenic impacts in local space. These factors led to the manifestation of large-scale degradation processes of the soil cover.

2.2. The ways to solve the problem

Modern methods of preventing degradation and restoration of disturbed soils in Moldova are summarized in publications (Boincean, Dent, 2020; Kapitalchuk, Kochurov, 2022; Krupenikov, 2008; Program, 2005; Soil erosion, 2001). Following these publications we can see that different types of soil degradation are interrelated. It means that their minimization can often be achieved with the help of the same measures. So many measures to overcome soil degradation can be considered universal.

When chemical, physical and biological degradation occurs, the framework structure of the soil and its genetic horizons are preserved. This provides a potential opportunity to eliminate such degradation. The main measures to minimize these degradation and restore soil fertility are: the use of sufficient amounts of mineral and organic fertilizers, the full use of plant residues, the alternation of crops, the use of special agrotechnical methods of tillage and phytomelioration (Krupenikov, 2008; Boincean, Dent, 2020). To prevent soil salinization during irrigation, it is necessary to observe irrigation standards and water with an acceptable salt content. To avoid compaction of the soil, the use of heavy machinery should be excluded.

An effective way to restore soil fertility is to use organic fertilizers. However, the last 30 years, the main supplier of organic fertilizers – animal husbandry in Moldova is in a state of crisis and cannot provide the necessary amount of manure. The inability to carry out this key measure does not allow us to effectively solve the problem of restoring soils that have undergone chemical, physical and biological degradation.

On areas where there is a shortage of biogenic trace elements, it is advisable to introduce appropriate micro-fertilizers. In this case, the use of micro fertilizers leads to an increase in the yield and quality of agricultural crops (Microelementele, 2016).

The process of vertical degradation is irreversible, since the vertical structure consisting of genetic soil horizons is destroyed. But even in this case, there are ways to restore heavily eroded soils.

There are two main directions for solving the problem of soil degradation associated with erosion: 1) to search the ways to stabilize and reduce erosion to an acceptable value; 2) to develop methods for restoring soils disturbed by erosion.

For stabilizing and reducing erosion are used well-known anti-erosion agrotechnical techniques, forest reclamation and hydrotechnical measures (Boincean, Dent, 2020; Kapitalchuk, Kochurov, 2022; Krupenikov, 2008; Program, 2005; Soil erosion, 2001).

During the Soviet period, successful experiments were carried out in Moldova to restore washed-away soils by applying a layer of natural soil materials (meliorants) 30-45 cm thick to the surface of the washed-away soil. The restored soils proved to be stable, and the yield of agricultural crops on the restored soils are increased twice (Kapitalchuk, Kochurov, 2022; Krupenikov, 2008; Program, 2005; Soil erosion, 2001).

On the territory of Republic of Moldova there are three main sources of meliorants for the restoration of washed away soils: 1) fertile soil layers removed during construction; 2) deluvial sediments accumulated during erosion in the lower parts of slopes, gullies and floodplains of rivers; 3) bottom sediments of reservoirs (Program, 2005).

Soils from construction sites are characterized by low quality, small amounts of meliorant and the remoteness of the construction site from recultivated soils.

Deluvial soils are located near eroded slopes and occupy an area of about 100 thousand hectares. Compared with eroded soils, they contain on average 1.5 times more phosphorus, molybdenum, copper and nickel, and the proportion of nitrogen in humus is 5%. Humus reserves in deluvial soils (264 million tons) can ensure the restoration of washed away soils on an area of 200 thousand hectares (Kapitalchuk, Kochurov, 2022; Krupenikov, 2008; Program, 2005; Soil erosion, 2001).

200-240 million tons of sediments have accumulated in the water bodies of Moldova. This raw material is enough for reclamation of 75,000 hectares of washed away soils. Reservoirs are often located in relief depressions near slopes with soil disturbed by erosion, which significantly reduces the costs of land reclamation (Soil erosion, 2001).

The effectiveness of soil restoration depends on the quality of the raw materials used for reclamation. Therefore, it is necessary to know the amount of chemical elements available for plants, which is contained in the raw material. The analysis carried out by the authors showed that the chemical composition of bottom sediments is poorly explored. There was especially little information about the content of trace elements in them.

The authors summarized the available data on the content of trace elements in bottom sediments in Moldova (Table 1), and additional studies were conducted (Table 2).

Table 1. The content of trace elements (mg/kg) in sediments of reservoirs and soils of Moldova

Mn	**Zn**	**Cr**	**Ni**	**V**	**Cu**	**Pb**	**Se**
The range of trace element content in the reservoirs of Moldova							
100-5620	24-220	8-263	7-217	0,7-257	4-398	5-137	<1-3
The range of trace elements in the soils of Moldova							
150-2250	10-166	25-145	5-75	15-165	2-400	5-30	0,01-0,86

Source: Kapitalchuk et. al., 2015.

Table 2. Content of elements (mg/kg) in sediments of water bodies and soil of the Dniester valleys

Fe	Mn	Zn	Cr	Ni	V	Cu	Pb	Se
Dubossary reservoir, n=8								
8600- 39600	347,5-2391,2	18,4-60,7	29,8- 52,5	21,1-52,5	18,1- 54,4	12,5- 39,1	10,2	0,136-1,095
Lower Dniester, n=14								
11801-16900	147,6- 887,8	9,6-210,3	14,7- 37,8	8,7-23,6	5,5-33,5	4,1-16,7	0,5-8,9	0,089-0,468
Kuchurgan reservoir, n=7								
3700-22700	17,0-1393,9	1,0-111,0	13,3-49,7	20,6-40,9	0,7-25,1	7,4-55,2		0,092-3,937
Ponds and small rivers, n=14								
12800- 29000	145,1- 1852,5	6,6-992,5	13,1-92,8	7,4-51,9	4,3-54,4	4,1-48,4	2,6-12,6	0,120-1,171
All water bodies, n=43								
3700-39600	17,0-2391,2	1,0-992,5	13,1-92,8	7,4-52,5	0,7-54,4	4,1-55,2	0,5-12,6	0,089-3,937
Concentrations of elements in the soil of the Dniester valleys								
12300- 37700	445,6- 1459,6	34,0-74,0	91	39	91	12,8-73,0	20	0,095- 0,345

Source: Kapitalchuk et. al., 2015.

It was found that the average number of elements in the bottom sediments is arranged in the following sequence: Fe > Mn > Zn > Cr > Ni > V > Cu > Pb > Se. At the same time, Fe and Mn, as well as Pb and Se always retain their position in this series. Metals Zn, Cr, Ni, V and Cu can change their place in the row depending on the specific geochemical situation.

Bottom sediments of different water bodies differ in the content of elements. For example, high concentrations of Fe, Mn, Zn, Cr, Cu are observed in sediments of small reservoirs and small rivers, Fe, Mn, V in the Dubossary reservoir, and Ni, Cu, Se in the Kuchurgan reservoir.

The amount of trace elements in sediments of water bodies in Moldova can be 20-25% higher than in soils in the catchment area. Concentrations of Zn, Cu, Pb, Ni, Mo, V at the bottom sediments of the Kuchurgan reservoir are 2-7 times higher in comparison with soils. However, in small water bodies located on the left bank of the Dniester River, the metal content at the bottom sediments is usually less than their concentration in undisturbed soils. This difference for the corresponding elements is: Fe – 8%, Zn – 5%, Cr – 45%, Ni – 16%, V – 68%, Cu – 8%, Pb – 62%. Only the amount of Mn at the bottom sediments was 9% higher compared to the soils of the region.

Thus, the bottom sediments of water bodies on the territory of Moldova are an important source of trace elements for the restoration of washed away soils.

Small ravines (less than 1 ha) are often formed on the slopes in Moldova. Methods and technologies of reclamation of such ravines in Moldova were widely used in the Soviet period. During this period, the technology of agricultural development of landslide slopes was also developed (Krupenikov, 2008; Soil erosion, 2001). The first way to solve this problem involved conducting comprehensive surveys, developing and implementing an expensive set of anti-erosion and soil-reclamation measures. The second way was most widely used, which provided for a small amount of soil-reclamation surveys, the development and implementation of cheap elementary landslide measures. Currently, 80% of the lands destroyed by landslides are included in the reserve fund for forest reclamation.

Boincean B. & Dent D. (2020) based on long-term experiments, have shown that in order to solve the problem of soil degradation, it is necessary to switch to a more sustainable agricultural management system based on the "conservative farming" paradigm.

CONCLUSION

Global biospheric degradation is the result of the integral manifestation of all particular degradation, their spatial combination and interaction on the scale of the entire biosphere or its large parts. These types of degradation are difficult to overcome and represent a dangerous phenomenon that undermines the stability of the functioning of the entire biosphere of the Earth.

Soil deflation on the territory of Moldova is poorly expressed, has a local character, dust storms are rare. The main methods of preventing soil deflation are widely known - this is the creation of a system of protective plantations and minimal non-fallow tillage.

It should be noted that, despite the difficult economic situation and political instability, certain steps are being taken in the Republic of Moldova to overcome soil degradation. However, these measures are of a private nature and are not able to affect radically the processes of soil degradation in this country.

The problem of soil degradation is of paramount importance for Moldova, since soils are the main natural resource of this country. The processes of soil degradation in this country have been well studied and technologies for soil restoration have been developed. However, economic difficulties and political instability do not currently allow us to comprehensively solve this urgent problem.

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