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METHOD OF REMEDIATION AND SUSTAINABLE USE OF SOILS TESTED IN THE REPUBLIC OF MOLDOVA

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Abstract

The system of conservative agriculture is not suitable for compacted soils of the Republic of Moldova, which need first loosening, a fact confirmed by recent researches. In the drought years, due to the high resistance to the penetration of the dry arable layer, the penetration of water and roots into the depths is impossible, which leads to the decrease of the agricultural crops yields. The use of green fertilizers (autumn and spring vetch, sown in an agricultural year as a `busy field` of 5-filds crop rotation), whose green mass is introduced into the soil as organic fertilizer, leads to the positive remediation of the quality status of this layer. As a result of applying the green fertilizers through disking for a period of 5 years showed that the balance of carbon and nitrogen in the soil became positive for future 3-4 agricultural years; the physical quality state of the arable layer became favorable for agricultural crops; the crop yield increase with 1.0-0.5 t/ha/year. In order to maintain the long-term quality status of the Mini-till cultivated soils, it is necessary that, starting with the third year of cultivation, the field should be sown again with vetch as an intermediate crop, used at the end of April or the beginning of May for next year as a green manure. This process must be repeated permanently once in three years, which will ensure that the soil quality condition is maintained in a favorable state and that the nitrogen fertilizer needs to be reduced to 60-70%.

Key words: *carbon balance, mini-till, remediation, soil, vetch.*

INTRODUCTION

Conservative agriculture, based on the No-till system of soil tillage, is not suitable for dehumidified, destroyed, compacted soils, which require first loosening in the Republic of Moldova (Cerbari, 2011; Wiesmeier et al., 2015). The basic indicators used to determine the variants used in the conservative agriculture system are (Руководство..., 1991):
- elimination of the plowing with the return of the furrows, totally or for a number of years;
- maintaining at the soil surface of vegetal debris, total or at least 30% of its total;
- reducing the number of soil tillage and other measures that ensure soil conservation.

The requirements of the conservative agriculture largely correspond to the No-till or Mini-till soil tillage variants that are recommended for implementation on the agricultural lands of the Republic of Moldova, together with other compartments thereof (weed control, disease and pests, organic and mineral fertilization etc.). The No-till variant of soil tillage provides for sowing directly in the stubble or on the ground with vegetal debris of the previous plant. The main working unit is the drill. The main working unit is the seed drill. The main element of the No-till drill is the coulter. It is stated that as a result of the implementation of the No-till working system the top layer of soil gradually becomes more structured, more loosed; an aero-hydric and food regime favorable to plants is formed; soil resistance to erosion is increased (Berca, 2011; Lal, 2011; Блэк, 1993; Agricultura..., 2009).

In the first 5-6 years, and if is necessary in the following years (once in 3 years), the subsoil is carried out at the depth of the soil postarable layer (10-30 cm) with the subsoiler aggregate to accelerate the process of loosening of this layer by the roots of the crop plants.

The *general objective* of the researches was to assess the quality status and production capacity of the degraded ordinary chernozems from southern Moldova by incorporating in the soil as organic fertilizer the green mass of 2 crop yields of vetch on a field used as a "busy field" (1 year) in - a 5-field crop rotation with the following crop alternation per year: "busy field" (2 crop of

vetch applied in the soil as a green organic fertilizer) → autumn barley → rapeseed → autumn wheat → sunflower.
The research aimed at the preventive restoration of the degraded properties of the former arable layer 0-30 cm of the soil, currently compacted, by the systematic use of green fertilizers in conjunction with the agrotechnical procedures for the implementation of the conservative agriculture, based on the No-till system.

MATERIALS AND METHODS

In order to assess the impact of the No-till implementation on the quality status of the ordinary chernozems of Southern Moldova, on the territory of the Larga Nouă commune, the Cahul rayon were studied by comparison the soils worked according to the variant with conventional technology and variant with conservative technology - No-till. The land selected for experimental plot organization was investigated pedologically (Canarache, 1990; Florea et al., 1987) in order to evaluate the initial state of soil quality after its work 2 consecutive years in according to the No-till technology (Figure 1).

Figure 1. Experimental polygon, used in the agricultural year 2013-2014 under autumn wheat sown with No-till seed drill

The land is located on the quasi-horizontal surface of the last (highest) terrace of the Prut River. The absolute altitude of the site of the soil semi-profiles is about 120-121 m. The last terrace of the Prut River on the territory of the Larga Nouă commune is practically not affected by the erosion processes. The agricultural lands are suitable for vineyards, orchards, cereals, vegetables for irrigation etc.
The soil cover of the terrace is made up of clayey ordinary chernozem with a moderately humiferous profile. The parent rock of soil genesis on the high terrace of the Prut River is made up of loess deposits of wind origin. The soils are typical for southern Moldova formed in arid conditions than the usual chernozems of Central Moldova (Leah, 2017).
After being placed in the field at the end of September 2014, the experimental plot was sown with a mixture of autumn vetch (80 kg/ha) and winter wheat (50 kg/ha). The total area sowed with vetch was 1.15 ha (Figure 2).

Figure 2. The experimental plot sown with autumn vetch

One hectare of autumn vetch has been sown for seeds. The experimental plot (strip) occupied 0.15 ha. The autumn vetch from the experimental plot was incorporated into the soil at the beginning of May through disking. On the same day, spring vetch were sown again and incorporated into the soil as a green fertilizer by disking and plowing at the end of September (Figure 3).

Figure 3. The first green mass yield of autumn vetch incorporated into the soil through disking

At the end of September, the second crop mass of spring vetch from the experimental plot was incorporated into the soil by disking and plowing (Figure 4).

Figure 4. The second green mass yield of spring vetch incorporated into the soil as a green fertilizer at the end of September through disking and plowing

RESULTS AND DISCUSSIONS

The intensive conventional agriculture of the period 1950-1990 led to the deterioration of the physical, chemical and biological quality of the soils. The plowing of the soil with the cormana plow in Moldova is carried out at a depth of 30-35 cm. The intensive agrotechnical works have contributed to intensifying the processes of dehumidification and deterioration of the natural soil structure. As a result, the arable layer has lost resistance to compaction.

At the same time, the existence after the land privatization period (1990 - present) of a practically unbalanced correlation between the used volume of the chemical and organic fertilizers does not ensure a major increase of the soil production capacity (Cerbari, 2010).

Chernozems of Moldova are characterized by fine textures and a not always favorable correlation of the granulometric fractions. The high clay content in the arable layer of soils in conditions of compaction resistance lack of its layers, leads to strong settling of the lower part of this layer for 1-2 years after passing to the minimum basic soil work. As a result of the compaction, when implementing conservative soil tillage systems, the lower part of the degraded arable layer is not penetrated by the roots of the crop plants, which leads to the decrease of the volume of physiologically active soil and crops yields (Leah, 2018).

The partial reduction of the negative influence of the secondary compaction of the arable soil layer during the first 5-7 years of implementation of the conservative agriculture system, based on the No-till or Mini-till soil tillage procedures, can be carried out by using the phyto-ameliorative and agro-technical procedures (Leah, 2018a; 2018b). These procedures, by increasing the flow of organic substance and periodically performing the subsoil, can contribute to the restoration of the structure and the gradual loosening of the compacted postarable layer.

At the moment, based on the situation existing in the republic, the restoration of the quality status of the arable layer is possible only by applied in the soil the green fertilizers and the secondary production of agricultural crops, at the same time with the mechanical loosening of the former arable layer 0-35 cm once at 3 years by subsoiling with chisel, "pinochio" or other type of subsoiler (Leah, 2016a; 2016b).

The situation regarding the implementation in Moldova of different basic tillage systems that protect the soil depends on the initial characteristics of the soil (Canarache, 1990), the provision of the territory with precipitation and the technical possibilities of the farmers.

The program of conservative agriculture provides for both the preventive restoration of the initial quality status of the properties of the degraded arable soil layer, as well as the monitoring of the properties changes in time and space.

The preventive research of the experimental plots soil gave the possibility to make the following conclusions:

- The agricultural soils located on the high terraces of the river Prut are characterized by a dusty-sandy clay texture, excellent in terms of their tillage and implementation of No-till or Mini-till technologies.
- As a result of the implementation during 2 consecutive favorable climatic years (2013 and 2014) on the territory of Larga Nouă commune, Cahul rayon of the system of conservative agriculture, based on the No-till technology of soil tillage, the agricultural crops were increased using more efficient soil moisture, conserved due to the layer of mulch formed on soil surface and the balanced fertilization of the crop plants (Figure 5).

The years 2013 and 2014 were favorable in terms of atmospheric precipitation and soil moisture during the vegetation period of agricultural crops.

Figure 5. Mulches on the soil surface after harvesting the seed of vetch (consisting from mixture of straw and grains vetch that shook)

After the preventive research the following conclusions were made:

- The soils investigated are poorly supplied with mobile phosphorus, moderately provided with mobile potassium and require the balanced application of the respective chemical fertilizers every year. The balanced application of chemical fertilizers complex has led to a slow change in soil fertility in a positive direction.
- The increase of the mobile phosphorus content in the arable layer 0-20 cm of the soil up to 2-3 mg/100 g soil should be done by autumn plowing until the implementation of the conservative agriculture system.
- The physical quality state of the soils worked No-till for 2 consecutive years has worsened: the soil has become strongly compacted and with high penetration resistance in dry state starting from 5 cm depth from the soil surface. The only 0-5 cm layer of soil left loose, consisting of a mixture of organic debris from the mulch layer and soil granules.

The incorporation into the 0-10 cm soil layer of the green mass of a vetch crop led to the modification of the physical quality state of this soil layer from unfavorable to very favorable, the penetration resistance of this soil layer from the large became very small. There was little change in the positive direction and the quality condition of the upper part of the layer 10-20 cm as a result of the disking and incorporation in the soil of the green mass of vetch up to the depth of 10-12 cm (Tables 1-3).

The physical quality state of the layer 0-20 cm radically has also been modified as a result of the incorporation into the soil of the green mass of two crop of vetch. The bulk density of this unfavorable one became very favorable, and the penetration resistance from large to very large became extremely low and low, which contributed to the easy penetration of the roots of autumn barley.

The structure (dry sifting) in the soil layers where the green mass was introduced (0-10 cm, one crop and 0-20 cm, two crops), as a result of this action and the proper tillage of the soil, became agronomically favorable. However, the hydrostability of the structure of soil layers 0-10 cm and 0-20 cm, in which the green mass of vetch was introduced, did not change radically and from very small became only small - with a more favorable step.

The content of organic matter in the soil layers where the green mass of vetch was introduced increased by about 0.16-0.26%. It is necessary to note that this organic mass with high nitrogen content, as a result of the microbiological processes in the soil, partially becomes gradually labile humus. The labile humus is not closely related to the mineral part of the soil and gradually compares easily to mineralize as a result of microbiology processes. However, the mineralization process of this labile humus occurs slowly, over several years, which ensures for a period of 4-5 years a normal activity of the microbiological processes in the soil and avoids the emergence of the "nitrogen starvation" that is influential, by usually, due to the low content of mobile nitrogen in the soil, necessary for microbes to mineralize the organic residues of previous crops (Sencovscaia and Cerbari, 2018).

The changes of the properties parameters of the ordinary chernozem in result of the incorporation in the soil of the green fertilizers in the 2016-2019 are presented in Tables 1-4. The average statistical ecopedological values of the quality status of ordinary chernozem were assessed according to the methodology developed by N. Florea et al. (1987) and A. Canarache (1990).

The No-tillage of soil together with the introduction of green fertilizers improves the vital activity and diversity of the edaphic fauna of the ordinary chernozem under the conditions of the Southern Moldova. In average, the number of invertebrates increases 6.0 times, Fam. *Lumbricidae* - 3.0 times, biomass - 2.3 and 2.2 times compared to plowing at depth 25-27 cm. The diversity of invertebrates has improved significantly, the number of families increasing from 2-5 to 4-12. Saprophages prevailed in the composition of the edaphic fauna.

Application of the No-tillage and introduction of green fertilizers in conditions of the Southern area of Moldova has positive effects on the microorganisms of the ordinary chernozem. The largest changes are in the 0-10 cm layer. There is an increase in microbial biomass by 2.0-2.1 times, the share of microbial carbon in the total content - by 1.8 times, the reserves of microbial biomass by 2.3 times compared to the plowing system. In total, the biomass of microorganisms in the 0-30 cm of postarable layer increases on average by 13.9% compared to the plowing (Sencovscaia and Cerbari, 2018).

The research results confirm that the preventive restoration of the quality state of the dehumified, destroyed and compacted arable layer is absolutely necessary to be carried out until the implementation of the conservative agriculture system, based on the No-till soil tillage technology (Сйорд et al., 2002).

Table 1. Content of agronomic structural aggregates in soil (2016-2019)

Horizon and depth, cm	Initial data, No-till - 2 years		Variant - the application in soil 1 yield of vetch				Variant - the application in soil 2 yields of vetch			
	2015, autumn		2016	2017	2018	2019	2016	2017	2018	2019
	value / assessing		value / assessing	value / assessing	value / assessing	value / assessing	value / assessing	value / assessing	value / assessing	value / assessing
Content of agronomically favorable structural aggregates 10-0.25 mm (dry sieving, %)										
Ahp1 0-5	75.0 good	65.0 good	73.9 good	72.2 good	77.4 good	75.9 good	74.5 good	75.1 good	77.6 good	75.1 good
Ahp1 5-10	55.0 moderate									
Ahp1 10-20	48.8 moderate		57.5 moderate	44.0 moderate	40.8 moderate	42.5 moderate	77.7 good	77.7 good	71.0 good	70.4 good
Ahp2 20-30	42.7 moderate		49.0 moderate	47.8 moderate	48.2 moderate	50.8 moderate	45.1 moderate	45.1 moderate	44.3 moderate	40.0 moderate
Content of favorable hydrostabile agronomic structural aggregates (wet sieving, %)										
Ahp1 0-5	31.9 small	24.3 small	31.6 small	21.6 small	23.2 small	25.6 small	31.4 small	27.3 small	29.8 small	29.2 small
Ahp1 5-10	16.7 very small									
Ahp1 10-20	14.7 very small		23.9 small	19.4 very small	26.4 small	26.2 small	23.6 small	25.5 small	28.0 small	24.2 small
Ahp2 20-30	13.3 very small		14.1 very small	18.2 very small	19.4 very small	17.0 very small	13.4 very small	14.6 very small	15.0 very small	14.4 very small

Table 2. The value of bulk density and total porosity in soil (2016-2019)

Horizon and depth, cm	Initial data, No-till - 2 years		Variant - the application in soil 1 yield of vetch				Variant - the application in soil 2 yields of vetch			
	2015, autumn		2016	2017	2018	2019	2016	2017	2018	2019
	value / assessing		value / assessing	value / assessing	value / assessing	value / assessing	value / assessing	value / assessing	value / assessing	value / assessing
The mean values of bulk density, g cm^{-3}										
Ahp1 0-5	1.01 very small	1.24 small	1.12 very small	1.21 small	1.22 small	1.24 small	1.18 very small	1.24 small	1.22 small	1.23 small
Ahp1 5-10	1.47 high									
Ahp1 10-20	1.48 high		1.44 high	1.48 high	1.46 high	1.47 high	1.21 small	1.26 small	1.28 small	1.37 moderate
Ahp2 20-30	1.49 high		1.49 high	1.49 high	1.45 mare	1.48 mare	1.50 mare	1.44 mare	1.45 mare	1.47 mare
The average values of total porosity, % v/v										
Ahp1 0-5	61.2 extrem-high	52.9 high	56.9 very high	54.0 high	55.1 high	53.2 high	54.6 high	52.9 high	53.2 high	53.6 high
Ahp1 5-10	44.5 moderate									
Ahp1 10-20	44.5 small		45.7 moderate	44.6 small	44.9 small	45.4 moderate	54.3 mare	52.8 mare	51.7 mare	48.7 moderate
Ahp2 20-30	44.4 small		44.2 small	44.4 small	45.7 moderate	44.8 small	43.8 small	46.3 moderate	45.3 moderate	45.2 moderate

Table 3. The values of resistance to penetration and humus content in soil (2016-2019)

Horizon and depth, cm	Initial data, No-till - two years		Variant - the application in soil 1 yield of vetch				Variant - the application in soil 2 yields of vetch			
	2015, autumn		2016	2017	2018	2019	2016	2017	2018	2019
	value assessing		value assessing	value assessing	value assessing	value assessing	value assessing	value assessing	value assessing	value assessing
Average values of resistance to penetration, kgf cm^{-2}										
Ahp1 0-5	5 very low	13 low	7 very low	8 very low	6 very low	6 very low	6 very low	11 low	6 low	5 very low
Ahp1 5-10	20 high									
Ahp1 10-20	20 high		17 moderate	19 moderate	19 moderate	19 moderate	7 very low	12 low	15 low	10 low
Ahp2 20-30	20 high		20 high	20 high	23 high	22 high	21 high	16 moderate	22 high	21 high
Average values of humus content, % v/v										
Ahp1 0-5	2.70 moderate	2.63 moderate	2.79 moderate	2.85 moderate	2.78 moderate	2.82 moderate	2.89 moderate	2.85 moderate	2.85 moderate	2.86 moderate
Ahp1 5-10	2.57 moderate									
Ahp1 10-20	2.52 moderate		2.67 moderate	2.71 moderate	2.65 moderate	2.69 moderate	2.84 moderate	2.83 moderate	2.81 moderate	2.82 moderate
Ahp2 20-30	2.45 moderate		2.47 moderate	2.49 moderate	2.47 moderate	2.47 moderate	2.49 moderate	2.52 moderate	2.50 moderate	2.51 moderate

Table 4. The average values of mobile phosphorus and potassium content in soil (2016-2019)

Horizon and depth, cm	Initial data, No-till - two years		Variant - the application in soil 1 yield of vetch				Variant - the application in soil 2 yields of vetch			
	2015, autumn		2016	2017	2018	2019	2016	2017	2018	2019
	value assessing		value assessing	value assessing	value assessing	value assessing	value assessing	value assessing	value assessing	value assessing
Average values of mobile phosphorus content, mg kg^{-1} of soil										
Ahp1 0-5	2.2 moderate	1.9 moderate	1.8 moderate	2.0 moderate	2.4 moderate	2.6 moderate	1.8 moderate	1.8 moderate	2.3 moderate	2.9 moderate
Ahp1 5-10	1.7 moderate									
Ahp1 10-20	1.5 low		1.2 low	1.3 low	1.2 low	1.0 low	1.8 moderate	1.5 moderate	1.4 low	1.8 low
Ahp2 20-30	1.3 low		1.2 low	1.2 low	0.9 very low	0.8 very low	1.1 low	0.9	1.2 low	1.3 low
Average values of exchangeable potassium content, mg kg^{-1} of soil										
Ahp1 0-5	31 high	27 optimal	20 optimal	21 optimal	32 high	22 optimal	25 optimal	24 optimal	33 high	24 optimal
Ahp1 5-10	22 optimal									
Ahp1 10-20	20 optimal		20 optimal	20 optimal	20 optimal	19 moderate	25 optimal	21 optimal	21 optimal	21 optimal
Ahp2 20-30	18 moderate		19 moderate	19 moderate	18 moderate	15 moderate	20 moderate	19 moderate	17 moderate	17 moderate

This can be achieved only by intensifying the organic matter flow in the arable layer of soils from any possible source, increasing the humus content, restoring the structure and stabilizing it loosening.

The most effective method to regenerate the degraded soils for Moldova at present is the systematic use of green fertilizers - autumn and spring vetch or peas consistently sown in an agricultural year on a "busy field", whose green mass is introduced into the soil as an organic green fertilizer concomitantly with the subsoiling being carried out once in 3 years at a depth of 30-35 cm of the former arable layer (Cerbari and Leah, 2016).

In the climatic conditions of Southern Moldova it is possible to use the autumn peas or vetch as an intermediate crop, sown in the middle of September and incorporated into the soil as an organic fertilizer through disking at the end of April or at the beginning of May.

After the implementation of the conservative agriculture system, based on the No-till technology of soil tillage, it is necessary to establish a permanent pedological monitoring on the fields tillage according to this technology in order to detect in time some negative phenomena and to carry out the measures to prevent and eliminate their consequences.

The research conducted in 2016-2019 showed that the introduction into the soil by disking in the agricultural year 2014-2015 of two green masses of autumn vetch, as intermediate crop, led to the restoration in the positive direction of the physical, chemical and biological properties of the arable layer 0-10 and 10-20 cm: the soil layer 0-20 cm became biogenic, the balance of humus in the soil used for 4 years under the basic crops became positive, the quality and quantity of agricultural production increased.

The economic efficiency of the tested method is presented by the crop yield every year:

The harvest of autumn barley in 2016 reached the size of 7.1 t ha^{-1}, the harvest increase by 2.2 t/ha/year, the cash value of the harvest increase: 2.2 t barley x 2200 lei = 4840 lei (MDL).

Rapeseed harvest in 2017 reached the size of 4.1 t ha^{-1}, the harvest increase - 1.0 t/ha/year, the cash value of the harvest increase: 1 t rapeseed x 7100 lei = 7100 lei (MDL).

The winter wheat harvest in 2018 reached the size of 4.6 t ha^{-1}, the harvest increase was equal to 0.8 t/ha/year: income was 0.8 t wheat x 3300 lei = 2640 lei (MDL).

The sunflower harvest in 2019 was 3.3 t/ha/year, the cash value of harvest increase by 0.5 t ha^{-1}: 0.5 t sunflower x 7000 lei = 3500 lei.

The total monetary value for 4 years of the basic crop yields increase was: 4840 lei +7100 lei +2640 lei + 3500 lei = 18580 lei/ha.

Total expenses for experimental field organization, seed procurement, sowing, incorporation into the soil the green mass of 2 crop of vetch = 6000 lei.

The net income for 4 years from the basic crops yields constituted: 18080 lei - 6000 lei = 12080 lei (MDL).

CONCLUSIONS

The implementation on the Southern area of Moldova the conservative agriculture system, based on the No-till technology of soil tillage, has led to the increase of agricultural crops production in the first two years as a result of more efficient use of soil moisture, due to the layer of mulch formed on the soil surface and the balanced application of complex fertilizers.

The 5-years experimental researches confirmed that the preventive restoration of the quality status of the dehumidified, destructured and compacted arable layer of ordinary chernozem is absolutely necessary to be carried out until the implementation of the conservative agriculture system, based on the No-till soil technology.

The recommended method of preventive restoration of the quality status of the arable soil layer, based on the use of leguminous crops as green organic fertilizer, has led to the remediation of the physical, chemical and biological quality of this layer, to the increase of the soil production capacity and created prerequisites for the successful implementation of the conservative agriculture system - No-till.

The implementation in the Republic of Moldova the conservative agriculture system, based on the use of green fertilizers in conjunction with the No-till or Mini-till technologies of soil tillage, contributes:

- to the establishment of the permanent organic matter flow and the gradual positive restoration of the physical, chemical and biological properties of the soils;
- at the increase of the agricultural crop yields by 20-30%;
- at the reduction of the nitrogen fertilizer requirement by at least 50%;
- to the reduce of chemical pollution of agricultural production and the environment.

Soil as a means of production is a poorly renewable resource, spatially limited and cannot be multiplied. The regeneration of the soil can only take place if it is properly worked, it is not over exploited until it is exhausted, the conditions of protection and conservation are respected and it is ensured in a permanent flow of qualitative organic substance in its arable layer. Otherwise, the soil, being vulnerable to numerous degradation processes, can be damaged or even destroyed.

At the same time, we must recognize that the restoration of the damaged soil covering is very difficult to achieve and requires an extremely long time, very high costs and cannot be executed during the life of a people generation. In this context, permanent monitoring of changes in soil quality status is absolutely necessary for timely implementation of measures to combat or mitigate the degradation processes of this important means of agricultural production.

In order to successfully implement this method of remediating the degraded arable soil layer, it is necessary to organize the system of non-polluting green fertilizers use in the agricultural sector of the Republic of Moldova and to create the seed base of legumes (autumn and spring vetch or peas).

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