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EFFECTS OF GREEN FERTILIZERS ON THE QUALITY STATUS AND PRODUCTION CAPACITY OF THE CAMBIC CHERNOZEM FROM MOLDOVA

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ABSTRACT

Chernozems Cambic from Central Moldova are subject to different forms of anthropogenic degradation. One of these is dehumification (loss of humus) and compaction of arable soil layers. In the recent situation regarding soil degradation of Moldova, the use of green fertilizers (leguminous) in crop rotation is the only possibility to remediate and maintain the quality status of the arable soils for the long term. Research was carried out over two farming years (2015-2016). In order to assess the quality status and production capacity of degraded cambic chernozems, two green mass harvest of vetch were incorporated into the soil as organic fertilizer on the field used for one year as an ”busy field” - sown with vetch two time (autumn 2014 and spring 2015), in the 5-field crop rotation (vetch-wheat-rapeseed-barley-sunflower). The research results showed that the incorporation into the soil by disking two harvests of green mass and vegetal debris of vetch (about 12,4 t ha^{-1}) as organic fertilizers led to the increase of humus content by 0.20%, compared to the control variant; to accumulation in the soil of 310 kg of nitrogen, of which 180 kg fixed from the atmosphere; synthesis of about 3 t ha^{-1} of humus or 1.7 t ha^{-1} of carbon; sequestration of about 6.3 t ha^{-1} of CO_2; a weakly positive balance of organic matter and nitrogen in the soil over 3-4 years was insured. On the plot where one harvest of green mass of vetch was incorporated into the soil as green fertilizers, the increase in the wheat harvest increased up 2.4 t ha^{-1}, and on the plot where two harvests of green mass of vetch were introduced into the soil, the harvest increase up 3.2 t ha^{-1}, the total harvest was 7.0 t ha^{-1}.

Key words: *Chernozem Cambic, Degradation, Organic matter, Green mass of vetch.*

INTRODUCTION

The contemporary arable cambic chernozems from Central Moldova inherited from the pedogenesis phase under the forest vegetation a differentiated textural profile, with high fine clay content in which the colloidal fraction dominates. Under the conditions of the existing agricultural system, these soils were subjected to the intensive process of dehumification and accelerated destruction of the arable layer. High clay content, dehumification and destruction accelerated secondary compaction of the arable layer (Canarache, 1990).The non-fertilization of chernozems with organic fertilizers, the insufficient use of chemical fertilizers, and the strong secondary compaction of the arable layer have led to a decrease in their production capacity. The main cause of the decreased compaction resistance of the arable layer of the investigated cambic chernozems is the insufficient flow of organic matter in soils. Organic fertilizers are not applied in these agricultural soils for the last three decades. The quantities of chemical and organicfertilizers used for crop fertilization are small and do not provide anequilibrated balance of nutrients in the soils (Cerbari, 2010).

Secondary production from agricultural crop harvesting, as a rule, is not incorporated into the soil and is used for other purposes or burned in fields. Under such conditions in all arable soils of Moldova, a profoundly negative balance of organic matter and nutrients in soil, especially phosphorus, was created. The unequilibrated balance of organic matter flow in the soil does not ensure large increases of agricultural crops yields due to the unfavourable physical state of the soils. A favorable long-term state of the soil physical quality can be created only by the existence of a permanent organic matter flow into the arable soil layer (Leah & Leah, 2018). The permanent organic matter flow can be ensured by systemically carrying out the following procedures in agricultural practice: the use of manure at a dose of 10-15 $t{\cdot}ha{\cdot}year^{-1}$ (currently only 50 $kg{\cdot}ha{\cdot}year^{-1}$ are used); repeated fallow (natural grassing or untilled) of degraded arable land (but this is impossible, that free land is not); the use of land under annual and perennial grasses (cannot be used extensively, since the livestock has been reduced by 6 times); The use of legumes (vetch, peas, beans, alfalfa, chickpeas, etc.) as an intermediate crop in field crop rotation - currently is the most rational procedure for degraded soils of Moldova (Leah, Cerbari, 2015).

The purpose of the researches was to test and demonstrate the phytotechnicalprocedure for increase the organic matter flow and remediate the degraded properties of chernozems in Central Moldova under the influence of green mass of vetch.

MATERIAL AND METHOD

The research object was chernozem cambic of Central Moldova from the agrochemical experimental station "Ivancea", Orhei district of the Institute of Pedology, Agrochemistry and Soil Protection "Nicolae Dimo". Variants of the experience: Witness (without the application of green fertilizers); with the incorporation of green fertilizers - vetch (*Vicia sativa*) – one harvest; with the incorporation into the soil – two harvests of vetch green mass. Predecessor culture was winter wheat. After the winter wheat harvest, in mid-July, the stubble was disking with the disc harrow at a depth of 8-12 cm (agrotechnical operation to perform the stubble field). The modification of the main properties of the arable soil layer was estimated by comparing the initial results obtained at the founding of experience (the control variant) with the results obtained on the experimental variants.

For modifications characteristic of the physico-chemical and agrochemical indicators of the arable cambic chernozem, classical methods adopted in the republic were used (granulometric composition (texture) - Pipette method, soil preparation by dispersion with Na pyrophosphate solution; bulk density – cylinder method; resistence to compactation – picnometr method; humus – Tiurin method; nitrogen – Kjieldali method; mobile phosphorus and potasium – Macighin method). The soil samples were collected from the depths: 0-10 cm, 10-20 cm, 20-35 cm, in which the soil properties were determined. To assess the quality status of investigated chernozem cambic, criteria developed by Canarache (1990) and Florea *et al.* (1987) were used.

The arable cambic chernozem is characterized by the profile type: *Ahp1→Ahp2→ Ah→Bhw1→Bhw2→BCk1→BCk2→Ck* (Fig.1).

Fig. 1. Profile of the arable cambic chernozem

Fig.2. Structural fragment of the compacted horizon Ahp2 (20-30 cm)

Ahp1 (0-20 cm) – the arable layer, dark gray with a brown hue, dry, loamy-clayey, crumby-cloggy, very porous, weakly cracked, weakly compact, many roots and organic debris, clear passage to the next horizon.

Ahp2 (20-35 cm) – the postarable layer, black with brown hue, damp, loamy-clayey, compacted, prismatic-cloggy, prisms are practically without pores, cracked, thin and rare roots, clear passage to the next horizon (Fig. 2).

Ah (35-50 cm)– dark gray with brown hue, damp, loamy-clayey, nuts-form grains, small and medium aggregates, compacted, porous, small, medium and fine pores, thin roots, gradual passage to the next horizon.

Bhw1 (50-71 cm) – dark brown, loamy-clayey, nuts-form, the nuts break down into grains, compacted, small and fine pores, few roots, rarely - insect holes, gradual passage to the next horizon.

Bhw2 (71-95 cm) – light brown, damp, loamy-clayey, poorly structured, crumbles into nuts-form aggregates, compacted, small pores and fine, rare roots, gradual passage to the next horizon.

BCk1 (95-117 cm) – yellow with brown hue and white color micelles of carbonates, loamy-clayey, unstructured, breaks easily, the beginning of the illuvial carbonatic horizon, compacted, porous, medium and fine pores, some crotovines appear, gradually passing.

BCk2 (117-130 cm)–carbonatic alluvial horizon, light yellow-brown hue, micelles of carbonates, rare concretes, loamy-clayey, unstructured, lightly crushed, compacted, small and fine pores.

Ck (>130 cm) – yellow, with white pseudo micelles, less carbonate (micelle) neoformations than in the BC horizon, clayey-loamy, weakly compacted, porous, small and fine pores, many crotovines.

RESULTS AND DISCUSSIONS

The arable cambic chernozems are characterized by loamy-clayey texture and physical clay content in the humiferous horizons - 60% and in the horizons BC and C - 56-58%. The clay content in horizons A and B varies within the limits of 39-40%, and in the horizons BC and C - within the limits of 36-38% (Tab.1).

Table 1. Texture of the arable cambic chernozem, "Ivancea" Experimental Station

The horizon and the depth,cm	Fraction size, mm and content, %							
	1.0-0.25	1.0-0.05	0.05-0.01	0.01-0.005	0.005-0.001	<0.001	<0.01	Ka*
Ahp 1 0-10	0.7	5.1	34.0	7.5	13.5	39.2	60.2	1.08
Ahp 1 10-20	0.7	6.9	32.2	7.6	13.6	39.0	60.2	1.08
Ahp2 20-35	0.8	6.8	32.0	7.8	13.4	39.2	60.4	1.08
Ah 35-50	0.5	6.7	32.8	7.1	13.2	39.7	60.0	1.10
Bhw1 50-71	0.4	7.4	32.1	8.4	11.9	39.8	60.1	1.10
Bhw2 71-95	0.6	5.6	33.6	8.3	12.4	39.5	60.2	1.09
BCw1 95-117	0.5	5.1	36.0	7.7	12.0	38.7	58.4	1.06
BCk2 117-130	0.5	5.0	38.1	7.4	12.4	36.6	56.4	1.01
Ck 130-150	0.5	5.1	38.3	7.5	12.5	36.1	56.1	1.00

Ka – the coefficient of argillisation (Cerbari, 2010)

The argillisation of the profile upper part of these soils is due to the modification of their hydrothermal regime in the process of use in arable. Texture as the main physical property of the soil plays an important role in determining most of the physical and chemical properties (Lal, 2011). The granulometric composition depend the soil production capacity, its agronomic and ameliorative characteristics, and the superior recovery technology. As texture is a virtually unchangeable property, agricultural and ameliorative technologies must adapt to the textural specificity of the soils (Berca, 2011).

The investigated cambic chernozems are characterized by high content of fine clay which, under conditions of dehumification and destruction of arable layer, is arranged for strong secondary compaction. According to Canarache (1990), *"loamy-clayey and clayey soils are characterized by large and very large quantities of inaccessible water, poor mechanical and thermal properties, tillage is hard, because have high swelling and contraction capacity, but have good chemical properties - high cation exchange and buffering capacity, high humus content"*. Other properties of these soils differ significantly depending on their structural state. The production capacity of the soils with fine texture, depending on the situations described above, varies, generally, from medium to small. These soils must be tilled in the optimum time, which is short, are generally receptive to deep ploughing; the necessary quality of the germinating bed is obtained with greater difficulty than on other soils (Cerbari, 2011). Thus, the investigated arable chernozems are a very difficult object of production in agriculture.

The total quantity of vetch green mass incorporated into the soil as green fertilizer (aerial and root mass) was 12.4 $t{\cdot}ha^{-1}$ of absolutely dry mass (Fig.3, Tab.2). The content of the main nutrients in the dry mass of vetch constituted: N - 2.5%, P_2O_5 -

0.6%, K_2O - 2.5%, C - 41.2% (Tab.2). During the vegetation period, the winter wheat plants on the experimental plots after the incorporation into the soil the vetch green mass differed from the wheat plants on the control plot by the following characteristics: more dark green color of leaves; greater thickness of the stem; the height of the spike with 20-30% higher than at the witness variant. The state of winter wheat plants at the beginning of July on the experimental plots, where the vetch green mass was incorporated in the soil is shown in Fig. 4.
According to the obtained data on the experimental variants, the change in the positive direction of the quality state of the structure is observed only for soil layer 0-10 (12) cm, formed by disking and mixing the artificial structural elements of this layer with the organic residues of the vetch. The modification of the quality status of the 0-10 cm arable layer under the incorporation in the soil of two green mass of vetch harvest is shown in Fig. 5.

Fig.3.The experimental strip of vetch - „busy field”

Fig.4. The winter wheat on the plots, where the vetch green mass was incorporated

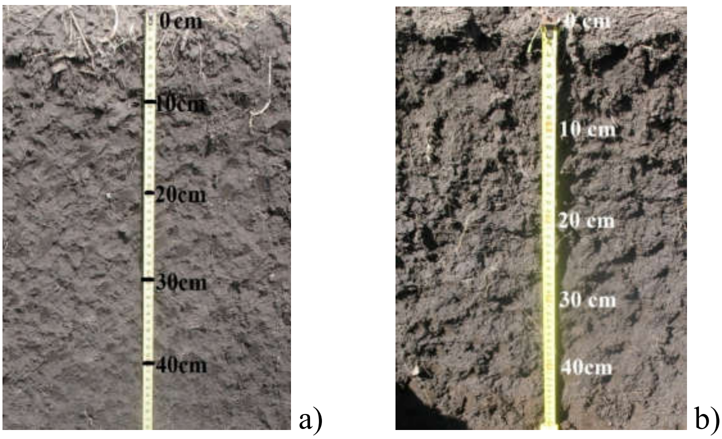

Fig.5. Chernozem cambic arable: *a) the control variant;*
b) the experimental variant, where two vetch harvests were incorporated into the soil

Table 2. Green mass harvest of vetch incorporated into the soil as fertilizer in 2015

Harvest	Green mass, t·ha^{-1}	Humidity, % of green mass	Dry mass, t·ha^{-1}	Ash	N	P_2O_5	K_2O	C
				% of dry mass				
Autumn vetch								
Main harvest	27.0	79.9	5.4	9.9	3.8	0.7	3.7	41.4
Vetch roots, total mass in 0-30 cm			2.2	14.8	1.8	0.5	1.5	41.1
Total aerial mass and roots of autumn vetch incorporated into the soil			7.6	11.3	3.2	0.6	3.1	41.3
Spring vetch								
Main harvest	9.6	64.2	3.4	10.3	1.5	0.5	1.5	40.9
Vetch roots, total mass in 0-30 cm			1.4	15.1	1.3	0.5	1.4	41.2
Total aerial mass and roots of spring vetch incorporated into the soil			4.8	11.7	1.4	0.5	1.5	411
Total vetch mass incorporated in the soil			***12.4***	***11.5***	***2.5***	***0.6***	***2.5***	***41.2***

Note: *From 12.4 t·ha^{-1} of vetch residues incorporated in the soil during 2015, about 3 t·ha^{-1} of humus will be synthesized (the humification coefficient - 0.25). The 12.4 t·ha^{-1} of vetch residues, incorporated in the soil, contain about 310 kg·ha^{-1} of nitrogen, 60% of which (180 kg·ha^{-1}) has symbiotic origin. The ratio C: N in the dry mass of vetch is 16.5.*

The modification of the physical and chemical properties of the cambic chernozem as a result of incorporation into the soil by discussing the green fertilizers is presented in the Tab.3. The soil layers 0-35 cm being destructured and dehumificated lost resistance to compaction. The values of the penetration resistance of the investigated soil layers correlate with their apparent density values and are low for the loose layers and large for the compacted underlying strata.In the soil layer 0-10 (12) cm, as a result of the incorporation into the soil of two vetch harvest, the content of organic matter increased by 0.20%, which is a positive change in one agricultural year. It is necessary to note that this organic mass is not yet humus and represents a labile organic matter, which is easily mineralized as a result of soil microbiology processes. A trend of positive modification is also detected for other indicators of the quality status of the chernozem under the influence of green fertilizers. However, some agrochemical properties of the soil practically have not changed.

The strategic problem remains the necessity to restore mobile phosphorus content in arable soils, reducing the reserve which in the arable layer becomes catastrophic. The use of vetch green mass as an organic fertilizer solves the problem of nitrogen in the soil, but not that of phosphorus (Leah, 2015). Research data confirms that green fertilizers, solving the problem of nitrogen in the soil, lead to increase in nitrogen content, which is ecologically positive.

Table 3. Modification of the average values of the physical and chemical properties of cambic chernozem as a result of incorporation into the soil by discussing the green fertilizers

Horizon and depth, cm	Control variant (initial data)		Variant with application into the soil of one crop of vetch		Variant with application into the soil of two crops of vetch	
	Value	Assessment	Value	Assessment	Value	Assessment
Average values of apparent density, g/cm^3						
Ahp1 0-10	1.24	low	1.21	low	1.16	very low
Ahp1 10-20	1.42	high	1.42	high	1.34	moderate
Ahp2 20-35	1.53	very high	1.52	very high	1.51	veryhigh
Ah 35-50	1.43	high	1.42	high	1.43	high
Average values of the total porosity, %						
Ahp1 0-10	52.3	high	53.5	high	55.4	very high
Ahp1 10-20	45.6	moderate	45.6	moderate	48.7	moderate
Ahp2 20-35	41.8	low	42.2	low	42.6	low
Ah 35-50	46.0	moderate	46.4	moderate	46.0	moderate
Average values of resistance to penetration, kgf/cm^2						
Ahp1 0-10	13	low	11	low	9	very low
Ahp1 10-20	21	high	20	high	15	low
Ahp2 20-35	26	very high	26	very high	24	high
Ah 35-50	20	high	21	high	21	high
Content of organic matter, %						
Ahp1 0-10	3.47	moderate	3.59	moderate	3.67	moderate
Ahp1 10-20	3.33	moderate	3.30	moderate	3.37	moderate
Ahp2 20-35	3.07	moderate	3.08	moderate	3.05	moderate
Ah 35-50	2.75	submoderate	2.71	submoderate	2.76	submoderate
Content of mobile phosphorus, mg 100g^{-1} of soil						
Ahp1 0-10	1.9	moderate	2.0	moderate	2.1	moderate
Ahp1 10-20	1.4	low	1.4	low	1.3	low
Ahp2 20-35	0.8	very low	1.1	low	1.0	very low
Ah 35-50	0.8	very low	0.8	very low	0.8	very low
Content of mobile potassium, mg 100g^{-1} of soil						
Ahp 1 0-10	31	high	33	high	33	high
Ahp1 10-20	26	optimum	23	optimum	21	optimum
Ahp2 20-35	22	optimum	19	moderate	18	moderate
Ah 35-50	22	optimum	18	moderate	18	moderate
Content of nitrate nitrogen ($N-NO_3$), mg 100g^{-1} of soil						
Ahp 1 0-10	0.3	extremely low	0.6	very low	0.4	extremely low
Ahp1 10-20	0.2	extremely low	0.2	extremely low	0.1	extremely low
Ahp2 20-35	0.1	extremely low	0.1	extremely low	0.1	extremely low
Ah 35-50	0.1	extremely low	0.1	extremely low	0.1	extremely low
Content of ammonium nitrogen ($N-NH_4$), mg 100g^{-1} of soil						
Ahp 1 0-10	3.9	high	4.8	high	4.3	high
Ahp1 10-20	3.6	high	2.8	moderate	3.9	high
Ahp2 20-35	3.2	high	2.4	moderate	3.0	high
Ah 35-50	2.3	moderate	2.5	moderate	2.2	moderate

The results show that 2016 year from the point of view of atmospheric precipitation amount (329-368 mm) for the first category of crops was very favourable (Tab.4). The winter wheat harvest formed mainly from the precipitation water account, which fell during the wheat vegetation period. In the Tab.3 the data on soil humidity for control variant and variants where two harvest of vetch were introduced into the soil as a green fertilizer are presented.

Table 4. Soil moisture (%) on experimental plots

Depth, cm	Witness plot,without incorporating the vetch into the soil (2 ha)		Experimental plot, with wheat after two harvests of vetch incorporated in the soil (2 ha)	
	22.03.2016	01.07.2016	22.03.2016	01.07. 2016
0-10	23.3	25.9	23.9	25.9
10-20	23.5	23.8	25.2	23.9
20-30	24.3	23.9	26.7	25.1
30-40	25.1	23.5	26.3	24.1
40-60	24,4	23.9	26.2	23.3
60-80	24.0	20.5	24.4	19.7
80-100	23.6	20.0	23.5	19.3
0-100 (average)	*24.0*	*22.4*	*25.0*	*22.4*
Total water reserves (mm) in the 0-100 cm layer of soil in periods of winter wheat vegetation				
-	***358***	***334***	***368***	***329***
Assessment of the total water reserves in the 0-100 cm layer of soil in different periods				
-	***high***	***moderate***	***high***	***moderate***

The basic criterion for assessment the changes in the quality status of soil are the reaction of agricultural crops to these changes, which are expressed by the state of sowing and the sown crop yields. The average harvest on the control plot was 3.8 $t \cdot ha^{-1}$ of winter wheat. On the plot where it was incorporated into the soil by disking one harvest of vetch green mass, the wheat harvest increased by 2.4 $t \cdot ha^{-1}$ and made up 6.2 $t \cdot ha^{-1}$, and on the plot where into the soil was introduced two harvest of vetch green mass, the wheat harvest addition made up 3.2 $t \cdot ha^{-1}$, the total harvest of winter wheat - 7.0 $t \cdot ha^{-1}$ (Tab.5).

Table 5. Autumn wheat harvest on the control and experimental variants in 2016

Variant	Average wheat harvest, $t \cdot ha^{-1}$ (grain moisture - 8%)	Crop increase compared to the control variant	
Control (without vetch incorporation)	3.8	$t \cdot ha^{-1}$	%
After incorporation of one vetch green mass into the soil	6.2	2.4	63
After incorporation of two vetch green mass into the soil	7.0	3.2	84

The experimented phytotechnical method led to the remediation of the quality status only soil layer 0-10 (12) cm, to the increase of the soils production capacity and created the premises for implementation of the conservative agriculture system, based on the mini-till technology.

Soil is an organo-mineral system that can ensure a high agricultural production capacity only if there is a permanent flow of fresh organic matter in it (Lal, 2011). Creating an equilibrated or positive balance of the organic matter in the soil is the main condition for maintaining its long-term fertility and avoiding the degradation of arable layer by dehumidification, destructured and excessive secondary compaction (Leah, 2016, 2018).

This can be achieved only by the regular application into the soil of organic fertilizers - manure or green manures (Cerbari, 2015). Researches for cambic chernozem have shown the possibility to remediate the soil quality by phytotechnical methods in combination with agrotechnical ones, forming a positive balance of carbon, nitrogen and humus in the soil, stopping the degradation processes of the arable layer and regulating CO_2 emissions from the soil (Wiesmeier *et al*, 2015).

The situation in the country regarding the soil quality state at the moment can be changed only by undertaking a series of legislative, organizational, financial and phytoameliorative measures. The obtained researches, allow to recommend that within a 5-field crop rotation - one field should be introduced as a "busy field" with a sidereal leguminous: 1-2-3 harvest of vetch (or other leguminous) incorporated in the soil as green fertilizer in one agricultural year per each field of crop rotation once in 5 years. The structure of the crop rotation can be as follows: busy field, occupied with leguminous crop → maize (corn) → winter wheat → winter barley or → sunflower (Leah *&* Leah, 2018). This procedure, used within any system of agricultural land tillage, will lead to the formation of anequilibrated balance of organic matter in the soil, to the remediation of the quality status of the soil and to increase its production capacity.

CONCLUSIONS

The researches established that as a result of the incorporation into the arable layer of the cambic chernozem in the agricultural year 2015-2016, two green masses of vetch of about 12.4 $t \cdot ha^{-1}$ of dry matter on the "busy field" ensured: accumulation in the soil of 310 kg of nitrogen, of which 180 kg is fixed from the atmosphere; synthesis of about 3 $t \cdot ha^{-1}$ of humus or 1.7 $t \cdot ha^{-1}$ of carbon; sequestration of about 6.3 $t \cdot ha^{-1}$ of CO_2; a weakly positive balance of the organic matter and nitrogen in the soil for 3-4 years; a significant increase of wheat yield.

In the layer 0-10 (12) cm, as a result of the incorporation into the soil of two harvests of vetch, the content of labile organic matter increased by about 0.20% compared to this content in the soil on the control plot. Concomitantly, the state of physical quality of this layer was restored in a positive direction.

On the plot where in the soil was incorporated by disking, one harvest of vetch green mass the wheat yield increased by 2.4 $t \cdot ha^{-1}$ and made up 6.2 t/ha, on the plot

with twoharvest of vetch harvest, the rate made up 3.2 t·ha^{-1}, the total harvest was 7.0 t·ha^{-1}.
The quality of the winter wheat grains was increased, the gluten content in the wheat harvested from the plots where in the soil as green fertilizer was introduced - made up 28%, and in the wheat from the control plot - 24%.
By systemic use of green fertilizers in combination with those of phosphorus and partially of potassium, it is possible to gradually restore the state of physical, chemical and biological quality of the soils and to increase sufficiently their agricultural production capacity. The problem is to organize the system of non-polluting green fertilizers use in the agricultural sector of the Republic of Moldova and to create the seeding base for autumn and spring vetch and other leguminous cultures.

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