Cercetări Agronomice în Moldova
Anul XXXX , Vol. 3 (131) / 2007

INVESTIGATIONS ON THE INFLUENCE OF CROP ROTATION AND ORGANO-MINERAL FERTILIZATION ON MAIZE YIELD AND PHYSICAL-CHEMICAL CHARACTERISTICS OF CAMBIC CHERNOZEM IN THE MOLDAVIAN PLAIN

C. AILINCĂI[*1], Despina AILINCĂI[1], Maria ZBANȚ[1], Ad. MERCUŞ[2], D. ȚOPA[2], M. CARA[2]
1 Agricultural Research and Development Station of Podu-Iloaiei, Iaşi
2 University of Agricultural Sciences and Veterinary Medicine of Iaşi

Received March 10, 2007

***ABSTRACT** – The paper presented the results of investigations concerning the influence of long-term fertilization (39 years) on some physical and chemical characteristics of Cambic Chernozem from the Moldavian Plain and on the yield of maize, placed under different crop rotations with perennial grasses and legumes. The 39 year use of the crop rotation peas-wheat-maize-sunflower+reserve field, cultivated with perennial grasses and legumes, has resulted in getting maize yield increase of 29% (1312 kg/ha), in comparison with maize continuous cropping. On slope lands, the high rate fertilization of maize crop ($N_{140}P_{100}$) has determined, in the latest ten years, an average yield increase of 93% (3086 kg/ha), against the control, and applying a rate of $N_{60}P_{40}$+30 t/ha manure resulted in getting a very close yield increase (95%, 3156 kg/ha). The long-term use of 4-year crop rotation + field cultivated with perennial grasses and legumes has determined a maize yield increase of 16 %, respectively, 800 kg/ha, and the improvement of physical and chemical characteristics of soil. In maize crop, fertilized with $N_{60}P_{40}$+30 t/ha manure, the rate of greater than 0.25 mm hydrostable aggregates was higher by 26%, against the control; placing maize in crop rotations with perennial grasses and legumes has resulted in increasing by 30% the rate of hydrostable aggregates, compared to maize continuous cropping. The 39 year use of 3 and 4-year crop rotations, which had perennial grasses and legumes in the crop structure, has determined the increase in the content of total carbon and mobile phosphorus from soil by 10% (1.7 C g/kg), respectively, 31% (11.8 P-AL mg/kg), in comparison with maize continuous cropping. A minimum supply level of mobile phosphorus in soil (37-72 ppm) in maize continuous cropping (39 ppm) and wheat-maize rotation (37 ppm) was maintained in case of annual application of*

[*] E-mail: scdapoduail@zappmobile.ro

a rate of $N_{100}P_{80}$. The total carbon content in Cambic Chernozem from the Moldavian Plain has registered significant increases at higher rates than $N_{140}P_{100}$, in case of organo-mineral fertilization and 4-year crop rotation + reserve field cultivated with perennial grasses and legumes. In maize continuous cropping and wheat-maize rotation, very significant values of the carbon content were registered only in case of organo-mineral fertilization, and in 4-year crop rotation + reserve field, cultivated with perennial legumes, in case of $N_{140}P_{100}$ fertilization.

Key Words: maize, long-term fertilization, Cambic Chernozem, crop rotation

REZUMAT - Cercetări privind influența rotației culturilor şi a fertilizării organo-minerale asupra producției de porumb şi a unor însuşiri fizico-chimice ale cernoziomului cambic din Câmpia Moldovei. *Lucrarea prezintă rezultatele cercetărilor privind influența fertilizării de lungă durată (39 ani) asupra unor însuşiri fizice şi chimice ale cernoziomului cambic din Câmpia Moldovei şi asupra producției la cultura porumbului, amplasată în diferite rotații cu plante de leguminoase şi graminee perene. Folosirea timp de 39 de ani a rotației mazăre – grâu – porumb – floarea-soarelui + o solă săritoare cu leguminoase şi graminee perene a determinat obtinerea unui spor de producție la porumb, în comparație cu monocultura de porumb, de 29% (1312 kg/ha). Pe terenurile in pantă, fertilizarea culturii de porumb cu doze mari de îngrăşăminte ($N_{140}P_{100}$) a determinat obținerea, în ultimii zece ani, a unui spor mediu de producție, comparativ cu martorul nefertilizat, de 93% (3086 kg/ha), iar aplicarea dozei de $N_{60}P_{40}$+30 t/ha gunoi a determinat obținerea unui spor de producție foarte apropiat (95%, 3156 kg/ha). Folosirea îndelungată a asolamentului de 4 ani + o solă cu plante amelioratoare de leguminoase si graminee perene a determinat obținerea unui spor de producție la porumb, comparativ cu rotația grâu-porumb, de 16 %, respectiv de 800 kg/ha, şi îmbunătățirea însuşirilor fizice şi chimice ale solului. La cultura porumbului, fertilizată cu $N_{60}P_{40}$+30 t/ha gunoi, procentul de agregate hidrostabile, mai mari de 0,25 mm, a fost mai mare, față de martorul nefertilizat, cu 26%, iar amplasarea culturii porumbului în rotații cu leguminoase şi graminee perene a determinat, în comparație cu monocultura de porumb, creşterea procentului de agregate hidrostabile cu 30%. Folosirea timp de 39 de ani a asolamentelor de 3 sau 4 ani, care cuprind în structura culturilor plante amelioratoare de leguminoase şi graminee perene, a determinat, comparativ cu monocultura de porumb, creşterea conținutului de carbon total şi de fosfor mobil din sol cu 10% (1,7 C g/kg) şi, respectiv, 31% (11,8 P-AL mg/kg). Menținerea unui nivel minim de aprovizionare cu fosfor mobil în sol (37-72 ppm) la monocultura de porumb (39 ppm) şi rotația grâu-porumb (37 ppm) s-a inregistrat în cazul aplicării anuale a dozei de $N_{100}P_{80}$. Conținutul total de carbon la cernoziomul cambic din Câmpia Moldovei a înregistrat creşteri semnificative la doze mai mari de $N_{140}P_{100}$, în cazul fertilizării organo-minerale şi la asolamentul de 4 ani + o solă săritoare cu leguminoase şi graminee perene. La monocultura de porumb şi rotația grâu-porumb, valori foarte semnificative ale conținutului de carbon s-au înregistrat numai în cazul fertilizării organo-minerale, iar la rotația de 4 ani + o solă săritoare cu leguminoase perene, şi în cazul fertilizării cu $N_{140}P_{100}$.*

Cuvinte cheie: cultura porumbului, fertilizare de lungă durată, cernoziom cambic, rotația culturilor

INTRODUCTION

In many countries, the latest research has investigated the diversification of cropping systems by increasing the rate of annual and perennial legumes within crop structure. Due to the process of the biological fixation of atmospheric N_2 , annual and perennial legumes determine the diminution of fossil energy use and greenhouse gas emissions, because of the decrease in nitrogen rates and in the need of external inputs and nitrogen losses from farming environment. Crop rotation will continue to be one of the most important components of the farming technological system, which contributes to rationing the consumption of fuel, water, fertilizers and pesticides and biological preparations for plant protection.

The experiments carried out on clayey soils from Waco (75% clay) and Bongeen (60% clay), situated at 40 km NE from Dalby, Australia, have shown that the introduction of alfalfa in crop rotations, during two from ten years, determines a good water capitalization and an improvement in soil structure and fertility. In both soils, the content of organic carbon from soil, at depth of 15 cm, has increased from 0.96% to 1.26% in alfalfa and 1.16 in annual crops from Waco and from 0.95 to 1.11% in alfalfa and 1.16% in annual crops from Bongeen (Dalgliesh, 2007). For clayey soils from Waco, Dalal R.C. has found that the level of organic matter from soil was in equilibrium when the supply of organic matter was of 1.4 t/ha/year (40% Carbon).

The investigations conducted at Saskatchewan in Canada, on a gray Luvisol with sandy-clayey texture, 5% organic matter and a pH of 7.1 (where the annual mean of rainfall and evapotranspiration is of 410 and 506 mm, respectively) have shown that the yield of wheat, placed in barley-peas-wheat-rape rotation, was of 2744 kg/ha under unfertilized and of 3786 kg/ha (+38%) at rate of N_{120} P_{30} K_{42} kg/ha. The quantity of straw, chaff and roots (at depth of 0-15 cm) in wheat crop was of 6728 kg/ha, under unfertilized, and 7691 kg/ha (+34.3%), at the rate of $N_{120}P_{30}K_{42}$ kg/ha (Malhi et al., 2006). The nitrogen fixed by wheat, placed in a 5-year crop rotation (barley-peas-wheat-rape) was of 76.8 kg (60.2 kg grains and 16.6 kg straw), under unfertilized, and of 146.3 (109.2 kg grains and 37.1 kg straw) at the rate of $N_{120}P_{30}K_{42}$. The average concentration of NO_3-N, determined in wheat in autumn, at depth of 0-60 cm, was of 0.83 mg N/kg soil under unfertilized, and 14.1 mg N/kg soil at the rate of $N_{120}P_{30}K_{42}$. The mass of total organic carbon from soil, at depth 0-15 cm, was of 58.72 Mg C ha^{-1} under unfertilized, has decreased until 56,79 Mg C ha^{-1} at rate of $N_{80}P_{30}K_{42}$, then increased to 59.96 Mg C ha^{-1} at rate of $N_{120}P_{30}K_{42}$ (Malhi et al., 2006).

Investigations conducted in long-term experiments at Rothamsted on a Typic Paleudalf (USDA), containing 250 g/kg clay, 570 g/kg loam and 180 g/kg sand, have shown that only at high fertilizer rates ($>N_{192}P_{35}K_{90}Mg_{35}$), a significant increase was found in the mass of total organic carbon and stable carbon from soil.

The results obtained have shown that all nitrogen treatments (96, 144, 192, 240, 288 kg/ha) have determined the increase in the mass of instable carbon, compared to unfertilized variant or to the one fertilized with $P_{35}K_{90}Mg_{35}$. Only at high nitrogen rates (192, 240, 288 kg/ha), significant increases of total carbon and stable carbon were registered. In wheat continuous cropping, the mass of total carbon from soil was of 10.3 g C_t/kg soil, under unfertilized, 11.21 g C_t/kg at rate of N_{96} $P_{35}K_{90}Mg_{35}$ (applied since 1852), 11.4 g C_t/kg at rate of N_{144} $P_{35}K_{90}Mg_{35}$ (since 1852), 12.0 g C_t/kg at rate of N_{192} $P_{35}K_{90}Mg_{35}$ (since 1968), 12.4 g C_t/kg at rate of N_{240} $P_{35}K_{90}Mg_{35}$ (since 1985). In wheat fertilized with 35 t/ha manure, the mass of total carbon has increased, against the unfertilized, (10.3 g C_t/kg) until 27.3 g C_t/kg, and in the control plot, used as hayfield, the mass of total carbon has increased until 51.8 g C_t/kg (Blair et al., 2006).

The diminution in the mass of organic carbon from soil, when lower rates than 180 kg N/ha were applied, was also noticed in long-term experiments carried out on sandy loam Mollisol from Nashua (which started in 1979) and on clayey-loam Mollisol from Kanawha (set up in 1954), at North of Iowa, USA. In sandy loam Mollisol from Nashua, applying a rate of 270 kg N/ha has resulted in increasing the mass of organic carbon, compared to unfertilized control, from 18.3 to 20.0 g C kg soil, in maize-soybean rotation and from 22.7 to 23.6 g C kg soil in maize-maize-oats-alfalfa rotation.

In clayey-loam Mollisol from Kanawha, the value of the mass of organic carbon, at the rate of 270 kg/ha N has increased, compared to unfertilized control, from 33.3 to 37.3 g carbon/ kg soil, only in case of maize-oats-alfalfa-alfalfa rotation (Russell, 2006**).** In both experiments, the capacity of cationic exchange and, especially, the values of calcium, magnesium and exchangeable potassium, have significantly decreased once with the increase in nitrogen rates. The exchangeable potassium was significantly influenced by cropping system. The average values of exchangeable potassium, found in maize continuous cropping, maize-soybean rotation and maize-maize-oats-alfalfa rotation, were of 141, 115 and 122 at Nashua and 262, 235 and 210 mg K kg soil at Kanawha. At Kanawha, in maize-oats-alfalfa-alfalfa rotation, the content of exchangeable potassium from soil has decreased to 217, in comparison with maize continuous cropping (262 mg K/kg), which was explained by lower potassium uptake by maize, compared to other crops and, especially, to alfalfa. The research carried out by Nelly Blair in long-term experiments with different crop rotations (set up in 1966), on a dark Vertisol and a reddish Vertisol from Tamworth, Wales, Australia, has shown that the crop rotations with cereals and forage legumes resulted in reduced decrease of carbon and nitrogen content from soil, compared to the hayfield plot, used as control.

From the determinations carried out on these two soil types, it was found that the mass of total carbon was between 13.2 and 15.6 g/kg in wheat continuous cropping, 13.6 and 15.0 g/kg in crop rotations with legumes, 15.6 and 18.22 g C_t /kg on alfalfa plot and between 26.4 and 36.6 g C_t /kg on hayfield plot (Blair et al., 2006). The crop rotation with cereals and alfalfa has also determined the increase in the content of instable carbon by 41%-65%, in the percentage of hydrostable aggregates by 45-126% and increase in non-saturated hydraulic conductibility by 43-87%, on the two soil types, compared to non-cultivated field.

On slope lands from Southern (Catanzaro, Calabria) and Central Italy (Siena, Tuscany), on Vertic Cambisols with clayey-sandy texture, in wheat continuous cropping the mass of total organic carbon, at depth 0-40 cm, was of 8.3 g/kg and, respectively, 12.7 g/kg. On plane fields from Northern Italy (Verona, Veneto), in maize continuous cropping, the mass of total organic carbon diminished to 9.3 g/kg. This diminution is very high compared to the fields cultivated with perennial grasses, at which the mass of total organic carbon was of 15.0 and respectively, 19.0 g /kg soil. On the same soils from the Mediterranean regions, with hayfields and bushes, the total content of carbon was between 18.7 and 45.7 g/kg soil (Papini et al., 2007). Therefore, on clayey-sandy slope fields, the content of organic carbon has decreased, according to the usage of the field (from Mediterranean regions with hayfields and bushes to cultivated fields) by 83-85 % in Southern Italy (Catanzaro, Calabria) and by 37-63% in Central Italy (Siena, Tuscany); the highest decrease was found in wheat and maize continuous cropping and in meadows (Papini et al., 2007). As a result of organic matter diminution, on intensively exploited areas from Italy, the degradation of soil quality is high and the content of organic carbon has reached, in many cases, values below 1%, which represents a stage of pre-desertification. The diminution in the content of organic carbon has resulted in the decrease of cationic exchange capacity and the increase of soil acidity.

The analyses carried out on soils from Central Italy concerning the content of organic matter from the 0-50 cm soil layer, have shown that the highest weight was represented by areas with low organic matter (1.2-2.2%), followed by the ones with mean content (2.3-3.0%), and by areas with very low (< 1.2) or very high content of organic matter (> 3.0) (Marchetti et al., 2007).

MATERIALS AND METHODS

Since 1968, at the Agricultural Research Station of Podu-Iloaiei, investigations were conducted on the influence of different crop structures and fertilizers on yield and soil fertility. The experiments were carried out on a 14% slope land, with Cambic Chernozem soil-type, which has a loam-clayey texture (420 g clay, 315 g loam and 265 g sand), a neuter to weakly acid reaction and a mean nutrient supply.

During 1997-2006, the climatic conditions were favourable to plant growing and development, during five years in wheat and six years in maize. The mean annual rainfall amounts, registered in the last 10 years, were higher, with values comprised between 96.2 and 182.4 mm, compared to the multiannual mean on 79 years (544 mm), in four years, and lower by 25.3-100.1 mm in four years.

Within the interval of January-September, the average amount of rainfall, registered in the last 79 years, was of 424.9 mm. During 1997-2006, the drought conditions have affected maize crop in four years, when differences were between 38.0 (1997) and 94.5 mm (2003), compared to the multiannual mean. Soil, on which physical and chemical analyses were carried out, was sampled at the end of crop vegetation period. The soil response was established potentiometrically in watery suspension with glass electrode, the organic carbon content was determined by Walkley-Black method, modified by Gogoasa, and multiplication by 1.724, while the content of mobile phosphorus from soil was determined by Egner-Riechm Domingo method, in solution of ammonium acetate-lactate (AL) and potassium was measured in the same solution of acetate-lactate (AL) at flame photometer.

The determination of water runoff, soil and nutrient losses by erosion was carried out by means of plots for loss control with the area of 100 m^2.

RESULTS AND DISCUSSION

The crop rotation is also important under conditions of an intensive technology, being the main measure for soil protection, crop phytosanitary protection and efficient capitalization of all technological factors.

Crop rotations with annual and perennial grasses and legumes have increased the biodiversity of agro-ecosystems, diminished the quantity of nitrogen-based fertilizers, contributed to the increase in soil fertility and diversified the options of farming management.

For increasing the efficiency of fertilizers and diminishing mineral element losses, by leaching, elements losses or fixing, the applied rates should be established differentially, according to soil characteristics, soil management factors, climatic conditions and needs of cultivated genotypes. The applied fertilizer rates should complete the stock of mineral substances from soil until a good quality and economically efficient production is obtained, under conditions of improving water and soil resources.

On loam-sandy fields from Nashua, Iowa, the use of maize-soybean rotation for 23 years has determined the increase by 28% (1852 kg/ha) of the average maize yield, in comparison with maize continuous cropping, during 1979-1998. Placing maize in maize-maize-oats-alfalfa rotation has resulted in getting an yield increase of 34% (2265 kg/ha). On loam-clayey fields from Kanawha Iowa, after 48 years of experiencing, the average yield increases obtained during 1985 – 1998, in maize continuous cropping were of 26% (1812 kg/ha) in maize-soybean rotation, 39% (2682 kg/ha) in maize-maize-oats-alfalfa rotation, and of 41% (2822 kg/ha) in maize-oats-alfalfa-alfalfa rotation (Mallarino and Rueber, 1999).

On the reddish Preluvosol from Moara Domnească, the highest maize yields, obtained in 2005 and 2006, were found in soybean-wheat-maize (7952 kg/ha) and sunflower-wheat-maize-maize+alfalfa rotations (7858 kg/ha), where yield increases of 44.1 (2434 kg/ha) and, respectively, 42.4% (2340 kg/ha) were obtained, compared to maize continuous cropping (Săndoiu, 2007).

The average maize yield, obtained in the last five years (2002-2006) in EU-25, on 9.368 million ha, was of 7050 kg/ha. In winter wheat, the average yield obtained in EU-25, during 2002-2006, on 22.302 million ha, was of 5430 kg/ha (Eurostat, 2007).

On Cambic Chernozem from the Moldavian Plain, placing maize in 3 and 4-year crop rotations with annual and perennial legumes, has resulted in getting yield increases of 24 – 29 % (1089 – 1312 kg/ha), compared to maize continuous cropping. Placing maize in 4-year rotation (peas-wheat-maize-sunflower)+ameliorative field, cultivated with perennial grasses and legumes, has determined yield increases of 16 %, respectively, 800 kg/ha, compared to wheat-maize rotation (which is the most commonly used crop rotation by farmers) (*Table 1*).

Table 1

Average maize yields obtained in the last 10 years, in the Oana hybrid

Fertilizer rate	Maize continuous cropping				Wheat-maize rotation			
	Yield		Dif. kg/ha	Signif. kg/ha	Yield		Dif. kg/ha	Signif.
	kg/ha	%			%	%		
N_0P_0	2734	100		-	3234	100		-
$N_{60}P_{40}$	3726	136	992	***	4143	128	909	**
$N_{100}P_{80}$	4971	182	2237	***	5598	173	2364	***
$N_{140}P_{100}$	5614	205	2880	***	6132	190	2898	***
$N_{60}P_{40}$+30 t/ha manure	5732	210	2998	***	6226	193	2992	***
Average	**4555**	**100**	**0**		**5067**	**111**	**512**	
Crop rotation								
Fertilizer rate	Peas-wheat-maize rotation				Peas-wheat-maize-sunflower+reserve field cultivated with perennial grasses and legumes			
	Yield		Dif. kg/ha	Signif.	Yield		Dif. kg/ha	Signif.
	kg/ha	%			%	%		
N_0P_0	3623	100		-	3712	100		-
$N_{60}P_{40}$	4865	134	1242	***	5076	137	1364	***
$N_{100}P_{80}$	6022	166	2399	***	6383	172	2671	***
$N_{140}P_{100}$	6829	188	3206	***	7073	191	3361	***
$N_{60}P_{40}$+30 t/ha manure	6879	190	3256	***	7090	191	3378	***
Average	**5644**	**124**	**1089**		**5867**	**129**	**1312**	
LSD 5% = 436 kg/ha; LSD 1 % = 584 kg/ha; LSD 0.1 % = 768 kg/ha								

Applying high fertilizer rates ($N_{140}P_{100}$) in maize has determined, in the last 10 years, an average yield increase of 93 % (3086 kg/ha), and the use of low mineral fertilizer rates ($N_{60}P_{40}$), together with 30 t/ha manure, resulted in getting an yield increase of 95% (3156 kg/ha).

The average maize yield, obtained during 1997-2006, in the wheat-maize rotation, under unfertilized, was of 3234 kg/ha, and in the crop rotation with four annual crops+reserve field, cultivated with perennial legumes, the yield was of 3712 kg/ha. The average yield increases, obtained in maize during 1997-2006, were between 11 and 29 % (512 – 1312 kg/ha), due to crop rotation, and between 34 and 95 % (1127 – 3156 kg/ha), due to applied fertilizer rates (*Table 2*).

Table 2

Influence of crop rotation and fertilizers on maize yield, during 1997 – 2006 (Oana hybrid)

Crop rotation	Maize yield		Dif kg/ha	Signif.	Fertilizer rate	Maize yield		Dif. kg/ha	Signif.
	kg/ha	%				kg/ha	%		
Maize continuous cropping	4555	100			N_0P_0	3326	100		
Wheat-maize rotation	5067	111	512	*	$N_{60}P_{40}$	4453	134	1127	***
Peas-wheat-maize rotation	5644	124	1089	***	$N_{100}P_{80}$	5744	173	2418	***
Peas-wheat-maize-sunflower+reserve field cultivated with perennial grasses and legumes	5867	129	1312	***	$N_{140}P_{100}$	6412	193	3086	***
					$N_{60}P_{40}$+30 t/ha manure	6482	195	3156	***
LSD 5 %			502					564	
LSD 1 %			674					752	
LSD 0.1 %			886					988	

The introduction of reserve fields cultivated with perennial legumes into crop rotations has determined yield increases and improvement in soil physical, chemical and biological characteristics. In maize cropping, the percentage of hydrostable aggregates was influenced both by rotation and by organo-mineral fertilization (*Table 3*). The highest rate of hydrostable aggregates was found at the $N_{60}P_{40}$+30 t/ha manure fertilization and in case of placing maize in 4-year crop rotation+reserve field cultivated with perennial grasses and legumes. At the mineral fertilization, significant differences of the rate of hydrostable aggregates were found when using high nitrogen and phosphorus fertilizer rates, which can be explained by the high amount of crop residues in maize continuous cropping and wheat-maize rotation. The fertilization with $N_{60}P_{40}$+30 t/ha manure has increased by 39% the rate of hydrostable aggregates in maize continuous cropping and by 21-23% in 3 and 4-year crop rotations with ameliorative plants of perennial grasses and legumes, compared to the unfertilized control. The average rate of hydrostable aggregates > 0.25 mm (%) in maize, fertilized with $N_{60}P_{40}$+30 t/ha manure, was higher by 26% (compared to unfertilized control) and by 12-30% higher in 3 and 4 year-crop rotations with ameliorative plants (compared to maize continuous cropping) (*Table 4*).

Table 3

Influence of crop rotation and fertilization on soil degree of macrostructural hydrostability

Treatment	Hydrostable aggregates > 0.25 mm (%) at depth (cm):				%	Dif.
	0-10	10-20	20-30	Average (0-30 cm)		
Maize continuous cropping						
N_0P_0	43.2	44.3	46.8	44.8	100	0
$N_{60}P_{40}$	44.6	45.7	46.7	45.7	102	0.9
$N_{100}P_{80}$	47.5	49.8	53.9	50.4	113	5.6^{x}
$N_{140}P_{100}$	48.9	53.4	55.2	52.5	117	7.7^{xx}
$N_{60}P_{40}$+30 t/ha manure	57.2	64.2	65.4	62.3	139	17.5^{xxx}
Average	48.3	51.5	53.6	51.1		
Wheat-maize rotation						
N_0P_0	41.2	42.9	44.3	42.8	100	0
$N_{60}P_{40}$	40.5	43.8	45.2	43.2	101	0.4
$N_{100}P_{80}$	40.9	45.6	51.3	45.9	107	3.1
$N_{140}P_{100}$	41.6	49.8	51.6	47.7	111	4.9^{x}
$N_{60}P_{40}$+30 t/ha manure	47.9	53.8	55.6	52.4	123	9.6^{xxx}
Average	42.4	47.2	49.6	46.4		
Peas- wheat-maize rotation						
N_0P_0	52.3	54.2	55.2	53.9	100	0
$N_{60}P_{40}$	53.2	54.2	56.3	54.6	101	0.7
$N_{100}P_{80}$	54.1	55.7	56.1	55.3	103	1.4
$N_{140}P_{100}$	55.0	56.3	57.2	56.2	104	2.3
$N_{60}P_{40}$+30 t/ha manure	62.8	66.3	70.5	66.5	123	12.6^{xxx}
Average	55.5	57.3	59.1	57.3		
Peas- wheat-maize-sunflower+reserve field cultivated with perennial grasses and legumes						
N_0P_0	56.4	64.9	66.1	62.5	100	0
$N_{60}P_{40}$	55.2	65.2	68.2	62.9	101	0.4
$N_{100}P_{80}$	57.1	69.3	69.7	65.4	105	2.9
$N_{140}P_{100}$	58.9	69.5	69.9	66.1	106	3.6
$N_{60}P_{40}$+30 t/ha manure	69.5	78.1	79.6	75.7	121	13.2^{xxx}
Average	59.4	69.4	70.7	66.5		
LSD 5% = 4.4%; LSD 1% = 5.9%; LSD 0.1% = 7.8%						

Table 4

The rate of hydrostable aggregates > 0.25 mm (%) in maize, placed in different crop rotations and fertilization systems

Treatment	Maize continuous cropping	Wheat-maize rotation	Peas-wheat-maize rotation	Peas-wheat-maize-sunflower + reserve field cultivated with perennial grasses and legumes	Background average	%	Dif.	Signif.
N_0P_0	44.8	42.8	53.9	62.5	**51.0**	100	0	
$N_{60}P_{40}$	45.7	43.2	54.6	62.9	**51.6**	101	0.6	
$N_{100}P_{80}$	50.4	45.9	55.3	65.4	**54.3**	106	3.3	
$N_{140}P_{100}$	52.5	47.7	56.2	66.1	**55.6**	109	4.6	
$N_{60}P_{40}$+30 t/ha manure	62.3	52.4	66.5	75.7	**64.2**	126	13.2	xxx
Rotation average	**51.1**	**46.4**	**57.3**	**66.5**				
%	100	91	112	130				
Difference	0	-4.7	6.2	15.4				
Significance			x	xxx				
	Total	**Crop rotation**	**Soil background**					
LSD 5%	4.4	5.1	5.7					
LSD 1%	5.9	6.8	7.6					
LSD 0.1%	7.8	9.0	10.0					

The analyses carried out on the evolution of soil response, after 39 years of experiencing, have shown that the significant diminution in the pH value was found at higher rates than 100 kg N/ha (*Table 5*). The lowest pH values were found in maize continuous cropping and wheat-maize rotation, which can be explained by high nutrient uptake by these crop rotations and unfavourable conditions in which the processes of nitrification and crop residue decay developed.

The results obtained have shown that the 5-year crop rotation with perennial grasses and legumes has limited the pH diminution (compared to the wheat-maize crop rotation), even under long-term use of high nitrogen fertilizer rates. After 39 years of experiencing, in a 4-year crop rotation+reserve field cultivated with perennial grasses and legumes, soil response was found within the limit of weakly acid (6.4-6.8), even when using high fertilizer rates (100-140 kg/ha) with acidifying effect, as ammonium nitrate.

Table 5

Influence of long-term fertilization and crop rotation on soil response (0-20 cm) at Cambic Chernozem from the Moldavian Plain

Treatment	Maize continuous cropping	Wheat-maize rotation	Peas-wheat-maize rotation	Peas-wheat-maize-sunflower + reserve field cultivated with perennial grasses and legumes	Soil background average	Difference	Signif.
N_0P_0	7	6.9	7.1	7.2	**7.1**	0.00	
$N_{60}P_{40}$	6.8	6.7	6.9	7	**6.9**	-0.25	
$N_{100}P_{80}$	6.2	6	6.5	6.8	**6.4**	-0.73	x
$N_{140}P_{100}$	5.6	5.6	6.1	6.5	**6.0**	-1.15	xx
$N_{60}P_{40}$+30 t/ha manure	6.9	6.9	7	7.2	**7.0**	-0.10	
Crop rotation average	**6.50**	**6.42**	**6.72**	**6.94**	**6.6**		
Difference	0	-0.08	0.22	0.44			
Significance							
	Total	**Crop rotation**	**Soil background**				
LSD 5%	0.39	0.50	0.59				
LSD 1%	0.62	0.76	0.88				
LSD 0.1%	0.90	1.09	1.25				

In maize continuous cropping and wheat-maize rotation, although a great amount of crop residues accumulated into soil, this supply of organic matter did not improve soil response. Applying high nitrogen rates as ammonium nitrate (100-140 kg/ha) has determined pH diminution (0-20 cm) to 6.0-5.6 in wheat-maize rotation and until 6.8-6.5 in peas- wheat-maize-sunflower+reserve field cultivated with perennial grasses and legumes.

The analyses conducted on soil samples, taken from the field on which the wheat-maize rotation had been used for 39 years, pointed out the worsening of some soil chemical characteristics. In comparison with 4-year crop rotation, in the wheat-maize rotation with ameliorating plants (annual and perennial legumes and perennial grasses), the average humus content from soil has diminished from 3.18 to 2.84 %, and the content in mobile phosphorus decreased from 50 to 35.4 ppm (*Tables 6, 7*).

Table 6

Influence of long-term fertilization and crop rotation on humus content from soil (%)

Treatment	Maize continuous cropping	Wheat-maize rotation	Peas-wheat-maize rotation	Peas-wheat-maize-sunflower + reserve field cultivated with perennial grasses and legumes	Soil background average	%	Diffe-rence	Signif.
N_0P_0	2.74	2.62	2.85	2.89	2.78	100	0	
$N_{60}P_{40}$	2.71	2.56	2.91	2.94	2.78	100	0.00	
$N_{100}P_{80}$	2.82	2.80	2.98	3.14	2.94	106	0.16	
$N_{140}P_{100}$	2.96	2.93	3.19^{x}	3.36^{xx}	3.11	112	0.33	x
$N_{60}P_{40}$+30 t/ha manure	3.35^{xxx}	3.27^{xxx}	3.47^{xxx}	3.59^{xxx}	3.42	123	0.64	xxx
Rotation average	2.92	2.84	3.08	3.18				
%	100	97	105	109				
Difference	0	-0.08	0.16	0.26				
Significance				x				
	Total	**Crop rotation**	**Soil background**					
LSD 5%	0.25	0.26	0.33					
LSD 1%	0.34	0.36	0.44					
LSD 0.1%	0.44	0.48	0.58					

The humus content from soil at the mineral fertilization has increased (in comparison with the control), by significant values only at high fertilizer rates ($N_{140}P_{100}$), in 3 and 4-year crop rotations with annual and perennial legumes (*Table 6*). In maize continuous cropping and wheat-maize rotation, applying mineral fertilizer at the rate of $N_{140}P_{100}$, did not result in significant differences of the humus content from soil (in comparison with unfertilized control); this demonstrated that within these crop rotations, maintaining a positive balance of the organic matter was done only by organo-mineral fertilization. In maize continuous cropping and wheat-maize rotation, maintaining a good supply in mobile phosphorus (37-72 ppm phosphorus) was done by the annual application of rates of $N_{100}P_{80}$. The 39 year use of 3 and 4-year crop rotations, which included ameliorating plants of perennial grasses and legumes in the crop structure, has determined a good degree of the mobile phosphorus supply in soil at the rate of $N_{60}P_{40}$ (*Table 7*).

Table 7

Influence of long-term fertilization and crop rotation on mobile phosphorus content from soil (P-AL, mg/kg)

Treatment	Maize continuous cropping	Wheat-maize rotation	Peas-wheat-maize rotation	Peas-wheat-maize-sunflower + reserve field cultivated with perennial grasses and legumes	Soil background average	%	Difference	Signif.
N_0P_0	12	11	13	15	12.6	100	0	
$N_{60}P_{40}$	27	25	36	39	31.4	249	19	xxx
$N_{100}P_{80}$	39	37	48	52	44.2	351	32	xxx
$N_{140}P_{100}$	52	49	62	68	57.8	459	45	xxx
$N_{60}P_{40}$+30 t/ha manure	61	55	69	76	64.8	514	52	xxx
Rotation average	**38.2**	**35.4**	**45.6**	**50**	**42.2**			
%	100	93	119	131	110			
Difference	0	-2.8	7.4	11.8				
Significance			xxx	xxx				
	Total	**Crop rotation**	**Soil background**					
LSD 5%	3.5	4.1	4.5					
LSD 1%	4.7	5.4	6.1					
LSD 0.1%	6.2	7.1	8.0					

The soil agro-chemical degradation is a complex process, which consists in quantitative and qualitative diminution in the stock of organic matter and allowable nutrients, in negative modification of nutrients balance and buffering capacity. The diminution in the organic matter from soil was the main factor influencing soil fertility and productivity, with negative consequences on plant supply in nutrients, degradation of structural aggregates and relations between soil and water.

The organic fertilizer supply and the introduction of crop rotations with perennial grasses and legumes are the main opportunities for maintaining a positive humus balance.

Analysing the data obtained by Nyeroud concerning the humus balance from 2% humus content soil, Gheorghe Lixandru has found that the annual balance of humus content from soil was positive only in the case of the field cultivated with perennial grasses and of manure application, and for recovering annual humus losses by mineralization from unfertilized field, 12.7 t/ha manure should be applied every year (Lixandru, 2006).

Table 8

Influence of long-term fertilization and crop rotation on mass of total carbon from soil (C, g/kg)

Treatment	Maize continuous cropping	Wheat-maize rotation	Peas-wheat-maize rotation	Peas-wheat-wheat-maize-sunflower + reserve field cultivated with perennial grasses and legumes	Soil background average	%	Difference	Signif.
N_0P_0	15.9	15.2	16.5	16.8	16.1	100	0	
$N_{60}P_{40}$	15.7	14.8	16.9	17.1	16.1	100	0.0	
$N_{100}P_{80}$	16.4	16.2	17.3	18.2^{x}	17.0	106	0.9	
$N_{140}P_{100}$	17.2	17.0^{x}	18.5^{xx}	19.7^{xxx}	18.1	112	2.0	x
$N_{60}P_{40}$+30 t/ha manure	19.4^{xxx}	19.0^{xxx}	20.1^{xxx}	21.4^{xxx}	20.0	124	3.9	xxx
Rotation average	16.9	16.4	17.9	18.6				
%	100.0	97	106	110				
Difference	0.0	-0.5	1.0	1.7				
Significance				xx				
	Total	**Crop rotation**	**Soil background**					
LSD 5%	1.2	1.4	1.5					
LSD 1%	1.6	1.8	2.1					
LSD 0.1%	2.1	2.4	2.7					

The data obtained have shown that in cereals rotation and in the crop rotation with annual legumes + cereals, the humus balance was negative, and by the introduction of the reserve field cultivated with perennial grasses and legumes, a positive balance was reached. For comprising the cumulated effects and the interactions between all the factors (crop rotation, soil tillage, fertilization, soil characteristics, temperature and moisture, etc.), which are involved in the processes of humification and mineralization of the organic matter, the balance of humus reserve from soil should be controlled in all the crops from rotations and in more rotation cycles.

Most of long-term investigations, carried out abroad, beginning with those from Rothamsted in England or from Halle in Germany, and in Romania, have studied the evolution of carbon content as influenced by crop rotation and different fertilization systems of soil tillage (Hera and Mihăilă, 1981; Săndoiu et al.,1996; Merbach, 2000; Lixandru, 2006, etc). The results obtained have shown that low rate mineral fertilization in intensive crop rotations could determine the diminution in the content of organic matter from soil, but under conditions of high rates, which covered the exportation of mineral elements through crop, according to soil characteristics, they determined the accumulation of high quantities of crop residues with positive effect on the organic carbon content from soil. In the last decade, many investigations have shown the special importance of different organic materials (manure, composts, and sewage sludge) on the carbon content from soil, on physical, chemical and biological characteristics and soil erosion (Agassi, 1996; Adesodum, 2001; Albiach, 2001).

The mass of total carbon from Cambic Chernozem in the Moldavian Plain has registered significant increases at higher than $N_{140}P_{100}$ rates, in case of organo-mineral fertilization and in 4-year crop rotation, which included ameliorative plants of perennial grasses and legumes (*Table 8*). In maize continuous cropping and wheat-maize rotation, very significant values of the carbon content were found only in the organo-mineral fertilization, in 4-year crop rotation + reserve field cultivated with perennial legumes and in $N_{140}P_{100}$ fertilization.

CONCLUSIONS

The 39 year use of the crop rotation with peas-wheat-maize-sunflower+reserve field cultivated with perennial grasses and legumes has resulted in getting an yield increase in maize of 29% (1312 kg/ha), compared to maize continuous cropping.

On slope lands, the maize fertilization with high fertilization rates ($N_{140}P_{100}$) has determined, in the last 10 years, an average yield increase (compared to the unfertilized control) of 93% (3086 kg/ha), and applying a rate of $N_{60}P_{40}$+30 t/ha manure resulted in getting a very close yield increase (95%, 3156 kg/ha).

The long-term use of 4-year crop rotation+reserve field with perennial grasses and legumes has determined an yield increase in maize of 16%, respectively, 800 kg/ha, in comparison with wheat-maize rotation, and the improvement of soil physical and chemical characteristics.

In maize, fertilized with $N_{60}P_{40}$+30 t/ha manure, the rate of greater than 0.25 mm hydrostable aggregates was higher by 26%, compared to unfertilized control, and placing maize in crop rotations with perennial grasses and legumes has increased by 30% the rate of hydrostable aggregates, compared to maize continuous cropping.

The 39 year use of 3 and 4- year crop rotations has determined the increase in the mass of total carbon and mobile phosphorus from soil by 10% (1.7 C g/kg) and, respectively, 31% (11.8 P-AL mg/kg), in comparison with maize continuous cropping.

A minimum supply level of mobile phosphorus in soil (37-72 ppm) in maize continuous cropping (39 ppm) and wheat-maize rotation (37 ppm) was found in case of applying the annual rate of $N_{100}P_{80}$.

The mass of total carbon on Cambic Chernozem from the Moldavian Plain has registered significant increases at higher than $N_{140}P_{100}$ rates, at organo-mineral fertilization and in 4-year crop rotation+reserve field cultivated with perennial grasses and legumes. In maize continuous cropping and wheat-maize rotation, very significant values of the carbon content were found only in organo-mineral fertilization, in 4-year crop rotation+reserve field cultivated with perennial legumes and in case of $N_{140}P_{100}$ fertilization.

REFERENCES

Adesodum J K A., Mbagwu J S C., Oti N., 2001- *Structural stability and carbohydrate contents of an ultisol under different management systems,* Soil Till. 60. 135-142

Agassi M., 1996 - *Soil Erosion, Conservation, and Rehabilitation,* Marcel Dekker, New York

Ailincăi C., **Jităreanu G., Bucur D., Ailincăi Despina, Zbanț Maria, Răus, L., Mercus Ad., 2006** - *Impact of treatments with fermented sewage sludge on soil fertility and quality of crop yield in the Moldavian Plain*, Scientic Works, series Agronomy, vol. 49, U.A.M.V. Iaşi, 329-337, ISSN 1454-7414

Albiach R., Canet R., Pomares F., Ingelmo F., 2001 - *Organic matter components, aggregate stability and biological activity in a horticultural soil fertilized with different rates of two sewage sludges during ten years,* Biores Technol, 77, 109-114

Avarvarei I., Jităreanu G., 1996 – *Amelioration and capitalization of salt and alkaline soils in Romania,* International Congress on Agricultural Engeneering, Madrid, vol. 2, p. 547

Blair Nelly, Faulkner R.D., Till A.R., Poulton P.R., 2006 - *Long-term management impacts on soil C, N and physical fertility,* Soil & Tillage Research 91 (2006) 30-38

Blair Nelly, Faulkner R.D., Till A.R., G.J. Crocker G.J. 2006 - *Long-term management impacts on soil C, N and physical fertility*, Part III: Tamworth crop rotation experiment, Soil & Tillage Research 91 (2006) 48-56

Campbell, C. A., Zentner, R. P., Selles, F., Jefferson, P. G., McConkey, B. G., Lemke R. and Blomert, B. J. 2005- *Long-term effect of cropping system and nitrogen and phosphorus fertilizer on production and nitrogen economy of grain crops in a Brown Chernozem.* Canadian Journal of Plant Science 85: 81–93

Dalal R.C., Strong, W.M., Weston, E.J. and Gaffney, J. 1991 - *Sustaining multiple production systems. 2. Soil fertility decline and restoration of cropping lands in subtropical Queensland.* Tropical Grasslands 25, 173-180

Dalgliesh N.P., Tolmie P. E., Probert M. E., Robertson M.J., Brennan L., Connolly R. D., Sutton G., Hole S., Taylor R., Grant J., Milne G., 2007 - *Incorporating lucerne leys into cropping systems on the clay soils of the Darling Downs,* Proceedings of the Australian Agronomy Conference, Australian Society of Agronomy

Eurostat 2007- *Agriculture and fisheries/Crops products*- Statistics in focus, Journalists can contact the media support service: Bech Building Office A4/125 L - 2920 Luxembourg

Hera Cr., Mihăilă V., 1981 – *Evolution of some soil agrochemical indices by fertilization*, Annals of ICCPT Fundulea, 47

Jităreanu G., Ailincăi C., Ailincăi Despina, Bucur D., Mercus A. – **2006** - *Investigations on the evolution of main chemical and biological characteristics of soil as influenced by technological factors and soil erosion,* Scientific Works, vol. 49, series Agronomy, USAMV Iaşi, p 319

Lixandru Gh., 2006 – *Integrated fertilization systems in agriculture,* Pim Press, Iaşi

Merbach W., Garz J., Schliephake W., Stumpe H., Schmidt L., 2000 - *The long-term fertilization experiments in Halle (Saale), Germany - Introduction and survey,* Journal of Plant Nutrition and Soil Science, Volume 163, Issue 6 , p 629 – 638

Malhi S.S., Lemke R., Wang Z.H., Chhabra Baldev S., 2006- *Tillage nitrogen and crop residue effects on crop yield, nutrient uptake, soil quality, and greenhouse gas emissions,* Soil & Tillage Research 90 (2006) 171-183

Mallarino A. P., and Rueber D., 1999 - *Crop rotation and nitrogen fertilization for crop production. P* 30-33. In Annual progress reports 1998. Northern research and demonstration farm. ISRF98-22. Iowa State Univ., Ames, IA

Marchetti A., Piccini C., **Francaviglia R., Santucci S., Chiuchiarelli I., 2007** – *Evaluation of soil organic matter content in Teramo province (Central Italy),* 5th International Congress of the European Society for Soil Conservation Palermo, June, 25-30.2007, Changing Soil in a Changing World: the Soil of Tomorrow, 222, ISBN 978-88-9572-09-2

Papini Rossella, Valboa G., Favilli F., Castelli F., L'Abate G., 2007 – *Land use influence on organic mater pool and chemical properties of soil developed in different Italian environments,* 5th International Congress of the European Society for Soil Conservation Palermo, June, 25-30.2007, Changing Soil in a Changing World: the Soil of Tomorrow, 228, ISBN 978-88-9572-09-2

Russell A., E., Laird D., A., Mallarino A., P., 2006 - *Nitrogen Fertilization and Cropping System Impact on Quality in Midwestern Mollisols,* Soil Sci. Soc. Am. J. 70:249-255

Săndoiu D.I., Dumitrescu Nicoleta, Ştefanic Gh., Obrişcă Mihaela, Gheorghiță Niculina, Ciontu C., Săndoiu Ileana Fulvia, 2007- *Influence of crop rotation and nitrogen fertilization on winter wheat and grain maize and of the reddish preluvosol fertility. Improvement, conservationa and capitalization of degraded soils by human interference,* "Ion Ionescu de la Brad" Publishing House, Iaşi