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THE LONG-TERM EFFECTS OF CROP ROTATION AND FERTILIZATION ON YIELD AND SOIL FERTILITY IN THE MOLDAVIAN PLAIN

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ABSTRACT – The investigations conducted during 1995-2009 at the Podu-Iloaiei Agricultural Research Station have studied the influence of different organo-mineral fertilization rates on wheat yield and soil agrochemical characteristics. Within the experiment, the following rotation schemes have been followed: 2-year rotation (wheat-maize) and 5-year rotation (bean – wheat – sunflower – wheat - maize). The organic fertilizers, applied together with mineral ones ($N_{50}P_{50}$+60 t manure/ha), have improved soil chemical characteristics and determined mean yield increases in wheat of 122% (1918 kg/ha), as compared with the unfertilized control. In the intensive rotations with cereals, with high annual consumption of nutrients, maintaining a good soil supply with organic carbon and mineral elements was done only by the organo-mineral fertilization ($N_{50}P_{50}$ or $N_{100}P_{100}$ + 40 t manure/ha). In 5-year crop rotation, the content of organic carbon from soil has diminished by approximate 2.1 g/kg/year in unfertilized control and by 0.90 g/kg/year at the rate of $N_{120}P_{80}$.

Key words: Cropping systems, Fertilization, Organic carbon, Wheat

REZUMAT – Efectele de lungă durată a rotației culturilor şi a fertilizării asupra producției şi fertilității solului în Câmpia Moldovei. Cercetările efectuate în perioada 1995-2009, la Staţiunea de Cercetare-Dezvoltare Agricolă Podu-Iloaiei, au urmărit influenţa diferitelor doze de îngrăşăminte organo-minerale asupra producţiei de grâu şi a însuşirilor chimice ale solului. În cadrul experimentului, s-au studiat următoarele scheme de rotaţie a culturilor: rotaţia de 2 ani (grâu-porumb) şi rotaţia de 5 ani (fasole – grâu – floarea – soarelui – grâu -porumb). Îngrăşămintele organice, aplicate împreună cu cele minerale ($N_{50}P_{50}$+60 t gunoi /ha), au contribuit la îmbunătăţirea caracteristicilor chimice ale solului şi au determinat obţinerea unor sporuri medii de producţie la grâu, comparativ cu varianta martor nefertilizată, de 122% (1918 kg/ha). În rotaţiile intensive cu cereale, cu un consum anual ridicat de

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elemente nutritive, menţinerea unei asigurări bune a solului cu carbon organic şi elemente minerale s-a realizat doar prin fertilizarea organo-minerală ($N_{50}P_{50}$ sau $N_{100}P_{100}$ + 40 t gunoi/ha). În rotaţia de 5 ani, conţinutul de carbon organic din sol a scăzut cu 2,1 g/kg/an la varianta martor nefertilizată şi cu 0,90 g/kg/an la doza de $N_{120}P_{80}$.

Cuvinte cheie: sisteme de cultură; fertilizare; carbon organic; grâu.

INTRODUCTION

The goal of many studies carried out in different countries, in the last period, was to improve the technological elements concerning soil fertilization, tillage and crop rotations with perennial grasses and legumes, which determine the increase in the content of organic carbon from soil and the diminution of soil erosion and the effect of greenhouse gases (Hera, 1999, Lal, 2006, Lungu , 2006, Yadav *et al.* 2008, Dumitru *et al* 2008; Meijide *et al.* 2009).

Many investigations conducted in different countries have shown that applying low rates of mineral fertilizers with nitrogen, phosphorus and potassium in wheat-maize rotation has determined the diminution in the content of organic matter from soil.

The diminution in the content of organic carbon from soil, due to mineral fertilization, was found in loam sandy fields from Nashua, USA, where lower than 180 kg nitrogen/ha were applied in maize-soybean rotation (Russell, 2006) and in clayey loam soils from Rothamsted, England, where lower rates than $N_{192}P_{35}K_{90}Mg_{35}$ were applied (Blair Nelly *et al.*, 2006).

Investigations conducted by Allmaras, 2006 on loam-sandy soils from Rosemount, Minnesota, have shown that applying rates of 200 kg nitrogen as ammonium sulfate [$(NH_4)_2$ SO_4]), contributed to the increase in the amount of organic residues from soil and determined the increase in the organic carbon content by 20% against the unfertilized control (Allmaras, 2006).

MATERIALS AND METHODS

Since 1968, the investigations conducted at the Agricultural Research and Development Station of Podu-Iloaiei have followed the influence of different crop structures, rotations and fertilizers on crop yield and soil fertility (*Fig. 1*). These experiments were carried out on a Cambic Chernozem with clayey loam texture (431 g clay, 314 g loam and 255 g sand), a neuter to weakly acid reaction and a mean nutrient supply. The content of organic carbon was determined by the Walkley-Black method, to convert SOM into SOC it was multiplied by 0.58. The content in 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 extract of acetate-lactate (AL) at flame photometer. ANOVA was used to compare the effects of treatments. In wheat, we have used Gabriela Variety.

Figure 1- The experiences with different systems of fertilization in wheat

RESULTS AND DISCUSSION

The rainfall amounts registered during 1995-2009 (January-June) were greater, as compared to the average of the last 82 years (249.6 mm), with values between 9.0 and 139.0 mm in 9 years, and lower by 39.5-120.2 mm, in 6 years. The rainfall amounts registered in the last 15 years, during September-December, have determined normal conditions for wheat growing in 8 years, and were lower, compared to the multiannual mean (161.5 mm), in 7 years.

The positive effect of applying manure and crop residues, together with moderate nitrogen rates, on crop yield and soil physical, chemical and biological characteristics was found in many regions with different climatic conditions and soils (Hera, 1999; Russell, 2006; Morari, 2008). From the analyses conducted at the Agricultural Research and Development Station of Podu-Iloaiei, we found out that the mean supply with mineral substances per ton of applied manure was of 9.7 kg N, 3.2 kg P_2O_5, 11.2 kg K_2O, 0.5 kg Ca, 0.9 kg Mg, 5 g B, 15 g Zn, 8 g Cu and 161 kg humic matter. The results of investigations conducted under various soils and climatic conditions showed that the long-term practicing of wheat-maize rotation has resulted in high nutrient consumption from soil, while soil physical, chemical and biological characteristics worsened; therefore, improvement measures are required. The obtained results concerning the influence of fertilization on wheat yield pointed out that mineral fertilizers resulted in getting mean yields, comprised between 2456 and 3124 kg/ha, according to rates, and by applying organic fertilizers together with mineral ones, they increased at 2784-3924 kg/ha (*Table 1*). The mean yield increases obtained during 1995-2009 in wheat crop, by the application of mineral fertilizers, were comprised

between 56 and 98% (878-1546 kg/ha), according to applied rates, and the residual effect of manure on the second year has resulted in getting yield increases of 30-61% (479-956 kg/ha). The mean yield increase obtained in wheat for each kg of a. i. of applied fertilizer was comprised, according to rates, between 7.7 and 17.6 kg. In wheat crop grown in two-year rotation, the mean yield increases obtained for each ton of manure were between 19.7 and 24.0 kg grains (the direct effect in maize and the residual effect in wheat).

Table 1 - Influence of organo-mineral fertilization on wheat yield in wheat-maize rotation (1995-2009)

Fertilizer rate	Yield		Difference kg/ha
	Kg/ha	%	
N_0P_0	1578	100	
20 t manure	2057	130	479
40 t manure	2364	150	786
60 t manure	2534	161	956
N_{50}	2456	156	878
N_{50} + 20 t manure	2784	176	1206
N_{50} + 40 t manure	3056	194	1478
N_{50} + 60 t manure	3214	204	1636
$N_{50}P_{50}$	2631	167	1053
$N_{50}P_{50}$ + 20 t manure	3021	191	1443
$N_{50}P_{50}$ + 40 t manure	3325	211	1747
$N_{50}P_{50}$ + 60 t manure	3496	222	1918
$N_{100}P_{100}$	3124	198	1546
$N_{100}P_{100}$ + 20 t manure	3426	217	1848
$N_{100}P_{100}$ + 40 t manure	3754	238	2176
$N_{100}P_{100}$ + 60 t manure	3924	249	2346
LSD 5% = 240; LSD 1% = 310; LSD 0.1% = 408 kg/ha			

The mean wheat yields obtained during 1995-2009, in 5-year crop rotation after bean (bean – wheat – sunflower – wheat - maize), were comprised between 2084 kg/ha (100%) at the unfertilized control and 4396 kg/ha (111%) at a rate of 120 kg N + 80 kg P_2O_5 /ha (*Table 2*). The application of higher than 80 kg/ha phosphorus rates did not result in obtaining significant yield increases. The yield increases obtained by increasing phosphorus rates from 80 to 120 kg/ha in this period were not statistically ensured. The unilateral fertilization of wheat crop grown after bean crop, only with nitrogen (N_{120}) or phosphorus (80 kg P_2O_5) rates, resulted in limitation of yield increases of 85 and 22% (1768-450 kg/ha), respectively. The mean yield increases obtained in wheat for each kg of applied nitrogen and phosphorus, calculated with regression equation, were of 14.287 and 6.442 kg.

Table 2 - Mean yields obtained in wheat crop grown in 5-year rotation, after bean, during 1995 – 2009

Fertilizer rate, kg/ha a.i.		Yield		Difference
Nitrogen	P_2O_5	Kg/ha	%	kg/ha
0	0	2084	100	
30	0	2678	129	594
60	0	3182	153	1098
90	0	3578	172	1494
120	0	3852	185	1768
0	40	2435	117	351
30	40	3146	151	1062
60	40	3685	177	1601
90	40	3986	191	1902
120	40	4153	199	2069
0	80	2534	122	450
30	80	3642	175	1558
60	80	3956	190	1872
90	80	4234	203	2150
120	80	4396	211	2312
0	120	2596	125	512
30	120	3821	183	1737
60	120	4086	196	2002
90	120	4297	206	2213
120	120	4416	212	2332
Mean		3538	125	
LSD 5% = 254; LSD 1% = 332; LSD 0.1% = 411 kg/ha				
$Y = 2294.2 + 14.287\ N + 6.442\ P$; $R^2 = 0.894$				

In wheat crop grown in 5- year crop rotation after sunflower, the mean obtained yields, during 1995-2009, were comprised between 1485 kg/ha (100%) at the unfertilized control and 3652 kg/ha (146%) at rates of 160 kg N + 80 kg P_2O_5 (*Table 3*). In wheat crop grown in 5-year rotation after sunflower, the mean yield increases obtained for each kg of a. i. of nitrogen and phosphorus applied, calculated with regression equation, were of 9.891 and 5.714 kg grains. The mean yield increases in wheat crop grown after bean (4396 kg/ha), compared to wheat crop grown after sunflower (3425 kg/ha), at the rate of 120 kg N +80 kg P_2O_5, were of 971 kg/ha (28.3%). On Cambic Chernozem of the Moldavian Plain, a very good supply with mobile phosphorus and potassium, in wheat - maize rotation (87 and 264 mg/kg), was done at the annual application of the rate of $N_{100}P_{100}$+ 40 t manure/ha (*Table 4*). In the intensive rotations with cereals, with high annual consumption of nutrients, maintaining a good soil supply with organic carbon and mineral elements is done only by organic and mineral fertilization ($N_{50}P_{50}$ or $N_{100}P_{100}$ + 40 t manure/ha).

The chemical analyses have shown that in wheat - maize crop rotation, by long-term application of high nitrogen rates, soil response became weakly acid (pH 5.6). In case of organic and mineral fertilization, the pH diminution was less pronounced (*Table 4*).

Table 3 - Mean yields obtained in wheat crop grown in 5-year rotation, after sunflower

Fertilizer rate, kg/ha a.i.		Yield		Difference kg/ha
Nitrogen	P_2O_5	Kg/ha	%	
0	0	1485	100	
40	0	2235	151	750
80	0	2534	171	1049
120	0	2873	193	1388
160	0	3248	219	1763
0	40	1865	126	380
40	40	2451	165	966
80	40	2848	192	1363
120	40	3126	211	1641
160	40	3359	226	1874
0	80	1896	128	411
40	80	2754	185	1269
80	80	3243	218	1758
120	80	3425	231	1940
160	80	3652	246	2167
0	120	2016	136	531
40	120	3092	208	1607
80	120	3392	228	1907
120	120	3549	239	2064
160	120	3695	249	2210
Mean		2837	100	
LSD 5% = 226; LSD 1% = 298; LSD 0.1% = 387 kg/ha				
$Y = 1702.8 + 9.891\ N + 5.714P$; $R^2 = 0.916$				

Table 4 - Main agrochemical indices of soil as influenced by organo-mineral fertilization, in wheat-maize rotation

Fertilizer rate	pH (H_2O)	Organic carbon, g/kg	P-AL, mg/kg	K-AL, mg/kg
N_0P_0	6.7	16.1	11	186
20 t manure	6.8	19.5	41	243
40 t manure	6.9	21.6	56	265
60 t manure	6.9	22.3	62	279
$N_{100}P_{100}$	5.6	17.9	69	179
$N_{100}P_{100}$ + 20 t manure/ha	5.9	19.8	79	268
$N_{100}P_{100}$ + 40 t manure/ha	6.1	22.6	87	264
$N_{100}P_{100}$ + 60 t manure/ha	6.3	23.1	92	267
LSD 5%	0.26	0.9	5.2	19
LSD 1%	0.37	1.3	8.3	27
LSD 0.1%	0.51	1.9	11.4	39

The organic carbon content from soil differentiated from 16.1 g/kg at the unfertilized variant to 23.1 g/kg, when applying a rate of $N_{100}P_{100}$ + 60 t manure/ha.

The positive effect of applying manure, together with moderate nitrogen rates, on crop yield and soil physical, chemical and biological characteristics was found in many regions with different climatic conditions and soils. In Gumpenstein (Austria) on Dystric Cambisol with a sandy loam texture (47% clay, sand 46% and 7% clay) content of organic carbon in the soil layer 0-20 cm, decreased or remained the same, compared to 1962 when this experiment started, in plots treated with straw Slurry, NP and NPK and increased by 10.15 g / kg soil in the variant treated with manure (240 kg N / ha / year) (Rajinder *et al.*, 2005). The soil organic carbon content for the agricultural land of Austria, obtained from the national electronic soil information system BORIS (Boden Rechnergestütztes Informtions System) showed the following ranking for soil OC content (0-50 cm) under different land use systems: vineyards (57.6 t C/ha), cropland (59.5 t C/ha), orchards/gardenland (78 t C/ha), intensive grassland (81 t C/ha) and extensive grassland (119 t C/ha) (Gerzabek *et al.,* 2005).

In wheat-maize rotation, the mass of organic carbon in Cambic Chernozem from the Moldavian Plain has registered significant increases at rates of $N_{100}P_{100}$ + 60 t manure/ha. In wheat-maize crop rotation, the mineral fertilization has determined, after 41 years of testing, the diminution in the content of organic carbon from soil by approximate 0.953 g/kg/year in unfertilized control and by 0.316 g/kg/year at the rate of 100 kg/ha nitrogen +100 kg/ha P_2O_5 *(Fig. 2)*.

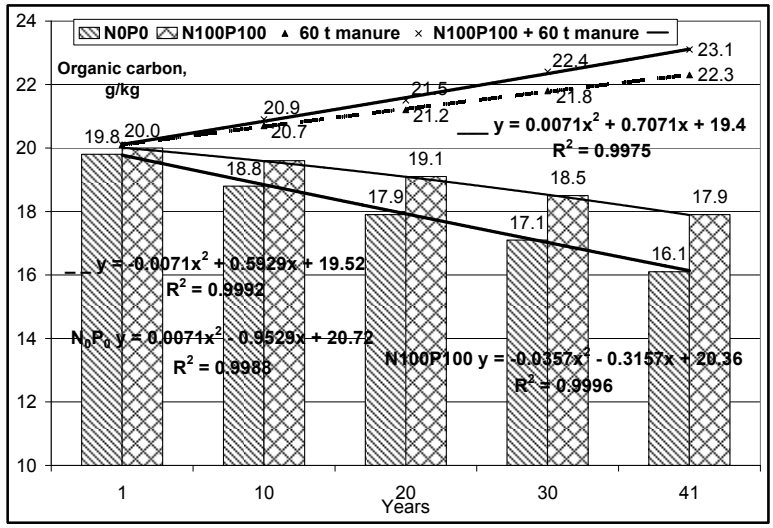

Figure 2 - Organic carbon content from soil, in wheat-maize rotation, at different fertilization rates with nitrogen, phosphorus and manure

In 5-year crop rotation, the content of organic carbon from soil has diminished by approximate 2.1 g/kg/year in unfertilized control, by 0.90 g/kg/year at the rate of $N_{120}P_{80}$ and by 0.28 g/kg/year at the rate of $N_{160}P_{120}$ *(Fig. 3)*.

After 43-year application of rates of 160 kg/ha nitrogen as ammonium nitrate, pH decreased from 6.8 to 5.4 *(Fig. 4)*. In 5-year crop rotation, applying a rate of $N_{160}P_{120}$ for 43 years has determined the pH decrease until the limit of moderately acid interval (5.4) and was maintained within the weakly acid interval (5.6-6.1) in unfertilized control and at the rate of $N_{100}P_{80}$.

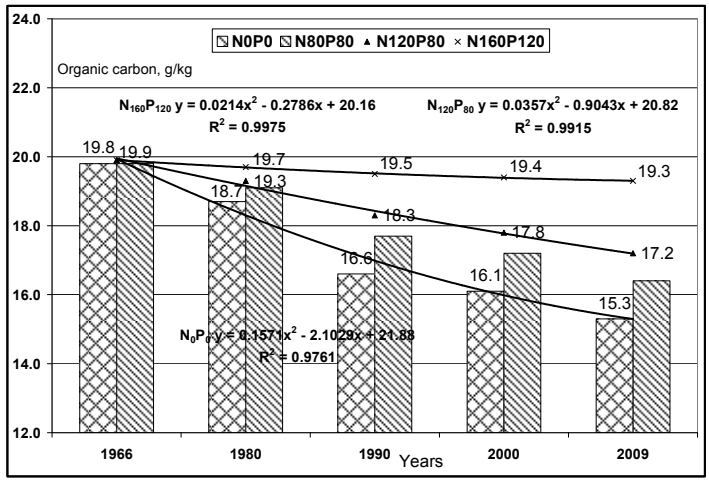

Figure 3 - Influence of long-term fertilization on organic carbon from soil

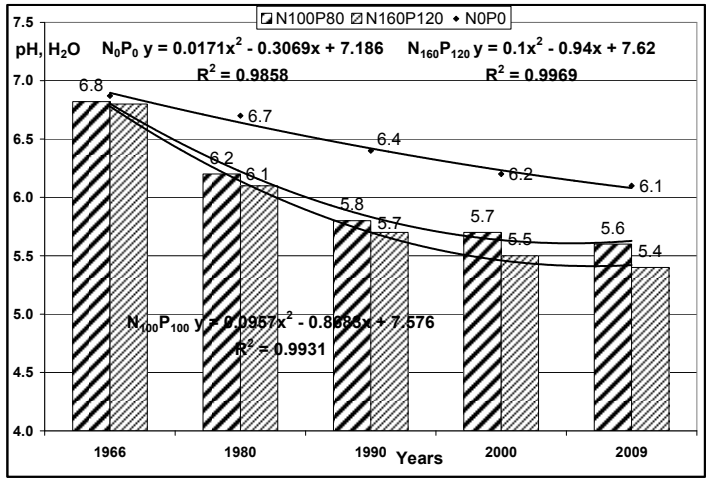

Figure 4 - Change of soil reaction, in 5-year crop rotation, at different fertilizer rates

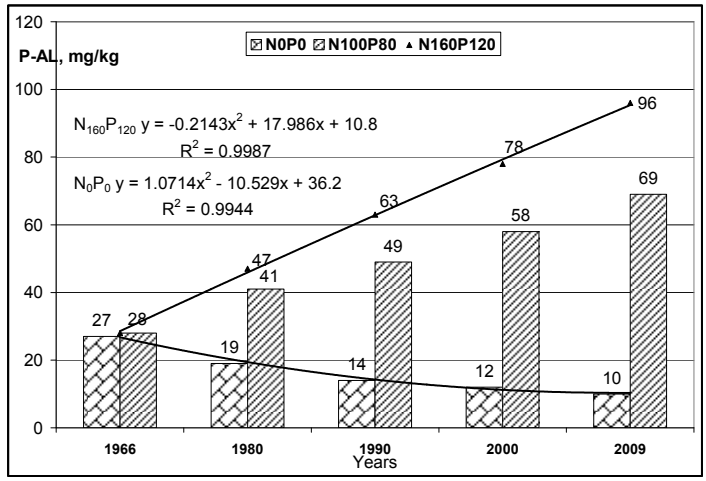

Figure 5 - Influence of long-term fertilization on mobile phosphorus from soil

The analyses on the mobile phosphorus content from soil have shown that in 5-year crop rotations, the supply condition was very good (69 mg/kg) in case of fertilization with 80 kg P_2O_5 *(Fig. 5)*.

CONCLUSIONS

In wheat crop grown in bean-wheat-sunflower-wheat-maize crop rotation, after sunflower, the mean obtained yields, during 1995 - 2009, were comprised between 1485 kg/ha (100%) at the unfertilized control and 3652 kg/ha (146%) at rates of 160 kg N +80 kg P_2O_5.

The mean yield increase obtained in wheat for each kg of a. i. of applied fertilizer was comprised, according to rates, between 7.7 and 17.6 kg grains in two-year rotation and 14.287 and 6.442 kg, in 5- year crop rotation.

On Cambic Chernozem of the Moldavian Plain, a very good supply with mobile phosphorus and potassium, in wheat - maize rotation (87 and 264 mg/kg), was done at the annual application of the rate of $N_{100}P_{100}$+ 40 t manure/ha.

In wheat-maize crop rotation, the mineral fertilization with 100 kg/ha nitrogen +100 kg/ha P_2O_5 has determined, after 41 years of testing, the diminution in the content of organic carbon from soil by approximate 0.32 g/kg/year.

In 5-year crop rotation, the content of organic carbon from soil has diminished by approximate 2.1 g/kg/year in unfertilized control and by 0.90 g/kg/year at the rate of $N_{120}P_{80}$.

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