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INFLUENCE OF ORGANO-MINERAL FERTILIZATION ON WHEAT AND MAIZE CROPS AND THE EVOLUTION OF SOIL FERTILITY UNDER LONG-TERM EXPERIMENTS IN THE MOLDAVIAN PLAIN

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ABSTRACT – The investigations conducted during 1996-2007 at the Podu-Iloaiei Agricultural Research Station have studied the influence of different organo-mineral fertilization rates on wheat and maize yield and soil agrochemical characteristics. In wheat-maize crop rotation, applying mineral fertilizers has resulted in getting mean yield increases. 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 of 125% in wheat and 108% in maize. The mean yield increases, obtained for each kg of a.i. of applied fertilizer, were comprised between 7.6 and 17.5 kg in wheat and between 13.0 and 28.1 kg in maize. In the intensive rotations with cereals, with high annual consumption of nutrients, maintaining a good soil supply with humus 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 the soils from the Moldavian Plateau, which are poor in organic matter and nutrients, the proper use of different organic resources may replace a part of high technological consumption, determined the improvement in the content of organic matter from soil and ensured better conditions for the capitalization of nitrogen fertilizers. On the Cambic Chernozem from the Moldavian Plateau, a good supply with mobile phosphorus in wheat and maize crops (37-72 mg/kg) was done in case of the annual application of a rate of $N_{100}P_{100}$, while a very good supply (72-91 mg/kg) was achieved at the rate of $N_{50}P_{50}$+60 t/ha manure.

Key words: fertilization, manure, nitrogen, phosphorus, wheat, maize, soil fertility

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REZUMAT – Influenţa fertilizării organo-minerale asupra culturilor de grâu şi porumb şi evoluţia fertilităţii solului, în condiţiile unor experimente pe termen lung în Câmpia Moldovei. Cercetările effectuate, în perioada 1996-2007, la Staţiunea de Cercetare-Dezvoltare Agricolă Podu-Iloaiei au urmărit influenţa diferitelor doze de fertilizare organo-minerală asupra producţiei de grâu şi porumb şi a însuşirilor fizice şi chimice ale solului. În rotaţia grâu-porumb, aplicarea îngrăşămintelor minerale a determinat obţinerea unor sporuri medii de producţie. Îngrăşămintele organice, aplicate împreună cu cele minerale ($N_{50}P_{50}$+60 t gunoi /ha), au contribuit la îmbunătăţirea caracteristicilor chimice sale solului şi au determinat obţinerea unor sporuri medii de producţie de 125% la grâu şi de 108% la porumb. Sporurile medii de producţie, obţinute pentru fiecare kg s.a. de îngrăşământ aplicat, au fost cuprinse între 7,6 şi 17,5 kg la grâu şi între 13,0 şi 28,1 kg la porumb. În cadrul rotaţiilor intensive cu cereale, cu un consum anual ridicat de elemente nutritive, menţinerea unei asigurări bune a solului cu humus 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 solurile din Podişul Moldovei, care sunt sărace în substanţă organică şi elemente nutritive, folosirea adecvată a diferitelor resurse organice poate înlocui o parte din consumul tehnologic ridicat, poate determina îmbunătăţirea conţinutului de substanţă organică din sol şi asigura condiţii mai bune de valorificare a îngrăşămintelor cu azot. Pe solul de tip cernoziom cambic din Podişul Moldovei, o asigurare bună cu fosfor mobil la culturile de grâu şi porumb (37-72 mg/kg) a fost realizată prin aplicarea anuală a unei doze de $N_{100}P_{100}$, iar o asigurare foarte bună (72-91 mg/kg) a fost realizată la doza de $N_{50}P_{50}$+60 t/ha gunoi.

Cuvinte cheie: fertilizare, gunoi de grajd, azot, fosfor, grâu, porumb, fertilitatea solului

INTRODUCTION

The organic fertilization has as goal to regenerate humic matters from soil and to improve soil physical, chemical and biological characteristics. By applying natural fertilizers, the contribution of nutritive mineral substances is much influenced by the way of gathering and preparing animal wastes, according to which the effects of soil and water polluted with pathogens, parasites and weeds may be controlled and prevented. 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 5.8 kg N, 2.5 kg P_2O_5, 8.6 kg K_2O, 0.4 kg Ca, 0.9 kg Mg, 5 g B, 14 g Zn, 7 g Cu and 159 kg humic matter. Therefore, the amounts of natural fertilizers, which must be applied, are determined according to the nitrogen consumption by crop, which capitalizes the direct effect of fertilization into the soil content in humus, clay and nutrients and into the quality of used organic substances (Borlan, 1990; Hera, 1984). 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 (Fresco, 2003; Russell, 2006; Morari, 2008). Other studies have shown that determining the rates of crop residues, which had to be applied in order to improve soil characteristics and diminish erosion, must take into account the

climatic conditions, soil type and cultural practices (Wright, 2007; Vineet, 2008). The results of investigations conducted under various soil and climatic conditions showed that the long-term practicing of wheat-maize rotation has resulted in high nutrient consumption from soil, while soil physico-chemical and biological characteristics worsened; therefore, improvement measures are required (Popescu, 1993; Mihăilă, 1996; Ailincăi, 2008; Jităreanu, 2008).

MATERIALS AND METHODS

The investigations conducted in stationary experiments, which were set up in 1967, under non-irrigated, have followed the influence of organo-mineral fertilization on wheat and maize yield and on the evolution of soil physical, chemical and biological characteristics. The experiments were conducted on a Cambic Chernozem, with loam-clayey texture, neuter reaction (pH 6.6-7.1) and 3.5% humus content. Applying organic fertilizers was done once in two years in maize, which has shown the direct effect of fertilization. The climatic conditions during 1996-2007 were favourable to plant growing and development in seven years, and unfavourable in the other five years (1996, 1997, 2000, 2003 and 2007), because of reduced rainfall. The climatic conditions in the Moldavian Plain were characterized by a mean multiannual temperature of 9.6 ^{o}C and a mean rainfall amount, on 80 years, of 542 mm, of which 161.2 mm, during September-December, and 380.8 mm, during January-August. The soil on which physical and chemical analyses were done was sampled at the end of plant growing. Soil response was determined in water suspension by potentiometrical means with glass electrode. The content of organic carbon was determined by the Walkley-Black method, and multiplied by 1.724; the content in mobile phosphorus from soil was determined by the 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. The determination of copper, manganese and zinc in extracts of soil was measured by flame and electro-thermal atomic absorption spectrometric method, with the International Standard ISO 11047:1998. ANOVA was used to compare the treatment effects. In wheat, we have used the Gabriela variety and in maize, the Podu Iloaiei- 110 hybrid.

RESULTS AND DISCUSSION

The obtained results concerning the influence of fertilization on wheat yield pointed out that mineral fertilizers resulted in getting mean yields, comprised between 2379 and 3032 kg/ha, according to rates, and by applying organic fertilizers together with mineral ones, they increased at 3176-3767 kg/ha (*Table 1*). The mean yield increases obtained during 1996-2007 in wheat crop, by the application of mineral fertilizers, were comprised between 58 and 101% (874-1527 kg/ha), according to applied rates, and the residual effect of manure on the second year has resulted in getting yield increases of 37-74% (550-1110 kg/ha). Applying organic substances with improving effect on soil has increased the efficiency of industrially made fertilizers; therefore, the organic fertilization has

resulted in getting mean yield increases in wheat of 95-150% (1430-2262 kg/ha). In maize, the mean yield increases obtained at the same period were comprised, according to rates, between 52 and 96% (1404-2605 kg/ha) in case of mineral fertilization, between 30 and 54% (814-1456 kg/ha) in case of organic fertilization and between 82 and 129% (2209-3401 kg/ha) in case of organo-mineral fertilization (*Table 2*). The mean yield increase obtained for each kg of a.i. of applied fertilizer was comprised, according to rates, between 7.6 and 10.7 kg in wheat and between 13.0 and 18.2 kg in maize. On the average, for each ton of manure, we have obtained 31.3 kg in maize and 22.6 kg in wheat (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 (1996-2007)

Fertilizer rate	Yield		Difference kg/ha	Significance	Yield increase kg grains /kg a.i. fertilizer and/or t manure
	Kg/ha	%			
N_0P_0	1505	100		-	
20 t manure/ha	2055	137	550	xxx	27.5
40 t manure/ha	2383	158	878	xxx	22.0
60 t manure/ha	2615	174	1110	xxx	18.5
N_{50}	2379	158	874	xxx	17.5
N_{50} + 20 t manure/ha	2713	180	1208	xxx	17.3
N_{50} + 40 t manure/ha	2988	199	1483	xxx	16.5
N_{50} + 60 t manure/ha	3176	211	1671	xxx	15.2
$N_{50}P_{50}$	2571	171	1066	xxx	10.66
$N_{50}P_{50}$ + 20 t manure/ha	2935	195	1430	xxx	11.9
$N_{50}P_{50}$ + 40 t manure/ha	3193	212	1688	xxx	12.1
$N_{50}P_{50}$ + 60 t manure/ha	3384	225	1879	xxx	11.7
$N_{100}P_{100}$	3032	201	1527	xxx	7.6
$N_{100}P_{100}$ + 20 t manure/ha	3333	221	1828	xxx	8.3
$N_{100}P_{100}$ + 40 t manure/ha	3579	238	2074	xxx	8.6
$N_{100}P_{100}$ + 60 t manure/ha	3767	250	2262	xxx	8.7
LSD 5% = 215; LSD 1% = 280; LSD 0.1% = 370 kg/ha Y (kg/ha) = 1788.3+11.91N+0.97P+14.34 t manure; R^2= 0.955, Obs.= 16					

Table 2 - Influence of organo-mineral fertilization on maize yield in wheat-maize rotation (1996-2007)

Fertilizer rate	Yield		Difference kg/ha	Significance	Yield increase kg grains /kg a.i. fertilizer and/or t manure
	Kg/ha	%			
N_0P_0	2709	100		-	
20 t manure/ha	3523	130	814	xxx	40.7
40 t manure/ha	3868	143	1159	xxx	28.9
60 t manure/ha	4165	154	1456	xxx	24.3
N_{50}	4113	152	1404	xxx	28.1
N_{50} + 20 t manure/ha	4513	167	1804	xxx	25.8
N_{50} + 40 t manure/ha	4836	179	2127	xxx	23.6
N_{50} + 60 t manure/ha	5135	190	2426	xxx	22.1
$N_{50}P_{50}$	4528	167	1819	xxx	18.2
$N_{50}P_{50}$ + 20 t manure/ha	4918	182	2209	xxx	18.4
$N_{50}P_{50}$ + 40 t manure/ha	5381	199	2672	xxx	19.1
$N_{50}P_{50}$ + 60 t manure/ha	5645	208	2936	xxx	18.4
$N_{100}P_{100}$	5314	196	2605	xxx	13.0
$N_{100}P_{100}$ + 20 t manure/ha	5684	210	2975	xxx	13.5
$N_{100}P_{100}$ + 40 t manure/ha	5953	220	3244	xxx	13.5
$N_{100}P_{100}$ + 60 t manure/ha	6210	229	3501	xxx	13.5
LSD 5% = 259; LSD 1% = 327; LSD 0.1% = 418 kg/ha Y (kg/ha) = 3155.09+18.73N+3.1P+18.59 t manure; R^2= 0.949, Obs.= 16					

From our studies, we found out that in wheat, placed in wheat-maize crop rotation, the mean annual amounts of nutrients extracted from soil, together with the harvest, have varied according to rates, between 47.5 and 116.8 kg at nitrogen, between 9.6 and 22.2 kg at phosphorus and between 35.8 and 93.7 kg at potassium (*Table 3*). Of the total amounts of nutrients extracted from soil together with the harvest (grains + straw), 74-81% of nitrogen, 51-73% of phosphorus and 53-57% of potassium were found in grains and the difference, in by-products.

In maize, the mean annual amounts of nutrients extracted from soil together with the harvest, have varied according to rates, between 58.1 and 153.3 kg at nitrogen, between 9.9 and 25.1 kg at phosphorus and between 49.1 and 131.7 kg at potassium. Among them, 67-76 % of nitrogen, 72-79% of phosphorus and 25-31% of potassium were used for the main production (*Table 4*). Both in wheat and maize, the organo-mineral fertilization has resulted in increasing the fertilizer capitalization indices, as compared to the application of only mineral or only

organic fertilization, at which the use for the main production was lower, as compared to the one of total biomass.

Table 3 - Mean annual amounts of nutrients exported from soil by wheat (grains + straw) and indices of their capitalization (1996-2007)

Fertilizer rate	Grains Kg/ha	Straw Kg/ha	Amounts of elements exported from soil, kg/ha			Capitalization indices		
			N	P	K	N	P	K
N_0P_0	1505	1802	33.8	6.9	26.2	0.79	0.75	0.57
20 t manure/ha	2055	2456	47.5	9.6	35.8	0.79	0.73	0.57
40 t manure/ha	2383	2853	60.3	11.1	46.2	0.81	0.73	0.57
60 t manure/ha	2615	3146	67.2	12.8	53.9	0.79	0.70	0.53
N_{50}	2379	2859	63.4	11.4	50.9	0.79	0.64	0.55
N_{50} + 20 t manure/ha	2713	3248	74.4	13.2	58.5	0.79	0.66	0.56
N_{50} + 40 t manure/ha	2988	3579	82.7	14.6	64.5	0.79	0.63	0.56
N_{50} + 60 t manure/ha	3176	3811	87.9	15.6	72.4	0.79	0.63	0.53
$N_{50}P_{50}$	2571	3026	68.5	13.1	58.1	0.79	0.67	0.53
$N_{50}P_{50}$ + 20 t manure/ha	2935	3520	81.3	15.3	68.4	0.76	0.58	0.54
$N_{50}P_{50}$ + 40 t manure/ha	3193	3829	88.5	16.7	74.4	0.76	0.58	0.54
$N_{50}P_{50}$ + 60 t manure/ha	3384	4062	93.8	18.1	78.9	0.76	0.58	0.54
$N_{100}P_{100}$	3032	3749	89.9	16.3	72.9	0.75	0.52	0.54
$N_{100}P_{100}$ + 20 t manure/ha	3333	4023	98.9	18.5	79.2	0.75	0.55	0.54
$N_{100}P_{100}$ + 40 t manure/ha	3579	4298	108.5	20.6	85.2	0.74	0.53	0.55
$N_{100}P_{100}$ + 60 t manure/ha	3767	4552	116.8	22.2	93.7	0.74	0.51	0.56
LSD 5%	178	214	4.9	0.9	3.9			
LSD 1%	250	300	6.8	1.3	5.5			
LSD 0.1%	337	405	9.2	1.7	7.4			

Table 4 - Mean annual amounts of nutrients exported from soil by maize (grains +by-products) and indices of their capitalization (1996-2007)

Fertilizer rate	Grains Kg/ha	By-products cobs+ shanks kg/ha	Amounts of elements exported from soil, kg/ha			Capitalization indices		
			N	P	K	N	P	K
N_0P_0	2709	3421	44.2	6.7	38.1	0.76	0.77	0.30
20 t manure/ha	3523	4298	58.1	9.9	49.1	0.76	0.78	0.31
40 t manure/ha	3868	4758	64.9	11.3	55.6	0.75	0.79	0.30
60 t manure/ha	4165	5248	72.2	12.2	62.3	0.74	0.78	0.30
N_{50}	4113	5347	75.1	12.8	63.8	0.72	0.77	0.30
N_{50} + 20 t manure/ha	4513	5867	84.5	14.0	71.2	0.72	0.77	0.29
N_{50} + 40 t manure/ha	4836	6384	92.6	15.7	80.8	0.71	0.77	0.28
N_{50} + 60 t manure/ha	5135	6881	100.8	16.8	88.6	0.69	0.77	0.28
$N_{50}P_{50}$	4528	6113	92.0	15.9	79.6	0.69	0.77	0.28
$N_{50}P_{50}$ + 20 t manure/ha	4918	6639	101.0	17.9	87.8	0.69	0.77	0.27
$N_{50}P_{50}$ + 40 t manure/ha	5381	7318	111.5	20.2	98.4	0.69	0.77	0.28

Fertilizer rate	Grains Kg/ha	By-products cobs+ shanks kg/ha	Amounts of elements exported from soil, kg/ha			Capitalization indices		
			N	P	K	N	P	K
$N_{50}P_{50}$ + 60 t manure/ha	5645	7790	121.0	21.4	104.4	0.67	0.77	0.28
$N_{100}P_{100}$	5314	7333	113.7	20.5	99.5	0.73	0.75	0.28
$N_{100}P_{100}$ + 20 t manure/ha	5684	7901	134.0	22.1	108.3	0.69	0.75	0.28
$N_{100}P_{100}$ + 40 t manure/ha	5953	8334	144.3	23.3	117.4	0.68	0.74	0.27
$N_{100}P_{100}$ + 60 t manure/ha	6210	8816	153.3	25.1	131.7	0.67	0.72	0.25
LSD 5%	259	344	5.1	0.9	4.3			
LSD 1%	327	435	6.5	1.1	5.5			
LSD 0.1%	418	556	8.3	1.4	7.0			

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 5.5). In case of organo-mineral fertilization, the pH diminution was less pronounced (*Table 5*). The humus content from soil differentiated from 2.82 at the unfertilized variant to 3.14 %, when applying a rate of $N_{100}P_{100}$. The organo-mineral fertilization has determined the increase in humus content until 3.76-4.32%. A good soil supply with phosphorus was done only at the annual application of a rate of at least $N_{100}P_{100}$. By applying rates of $N_{100}P_{100}$, together with organic fertilizers, the phosphorus content from soil reached a very good supply level (78-91 ppm).

Investigations conducted in long-term experiments at Rothamsted 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 (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 the long-term experiments carried out on sandy loam Mollisol from Nashua and on clayey-loam Mollisol from Kanawha at North of Iowa, USA (Russell, 2006).

The analyses carried out on the evolution of microelements content from soil (boron, zinc and copper) showed that in wheat-maize crop rotation, the probability of nutrients deficits seemed to be very high when only the mineral fertilization was used, while the organo-mineral fertilization had a positive influence on plant nutrition with microelements. Applying high nitrogen rates, which magnify soil acidity, has increased the manganese content from soil, which reached 162 ppm Mn, determining plant toxicity. Applying rates of $N_{100}P_{100}$ + 40 t manure/ha has resulted in the accumulation of mobile phosphate stock in soil of 86 ppm and the microelement content (mobile forms from soil) was of 6.5 ppm at Cu, 0.58 ppm at B, 2.5 ppm at Zn and 148 ppm at manganese (*Figure 1*).

Table 5 - Main agrochemical indices of soil as influenced by organo-mineral fertilization, in wheat-maize crop rotation, after 40 years of testing

Fertilizer rate	pH (H_2O)	Humus, %	P-AL, ppm	K-AL, ppm
N_0P_0	6.6	2.82	9	174
20 t manure/ha	6.7	3.09	39	239
40 t manure/ha	6.8	3.26	52	242
60 t manure/ha	6.9	3.48	59	253
$N_{50}P_{50}$	5.8	3.04	57	178
$N_{50}P_{50}$ + 20 t manure/ha	5.9	3.29	69	249
$N_{50}P_{50}$ + 40 t manure/ha	6.2	3.69	74	254
$N_{50}P_{50}$ + 60 t manure/ha	6.4	3.76	77	263
$N_{100}P_{100}$	5.5	3.14	72	167
$N_{100}P_{100}$ + 20 t manure/ha	5.7	3.49	78	251
$N_{100}P_{100}$ + 40 t manure/ha	5.8	4.21	86	263
$N_{100}P_{100}$ + 60 t manure/ha	5.9	4.32	91	269
LSD 5%	0.24	0.15	4.7	17
LSD 1%	0.35	0.22	7.1	25
LSD 0.1%	0.52	0.32	10.2	37

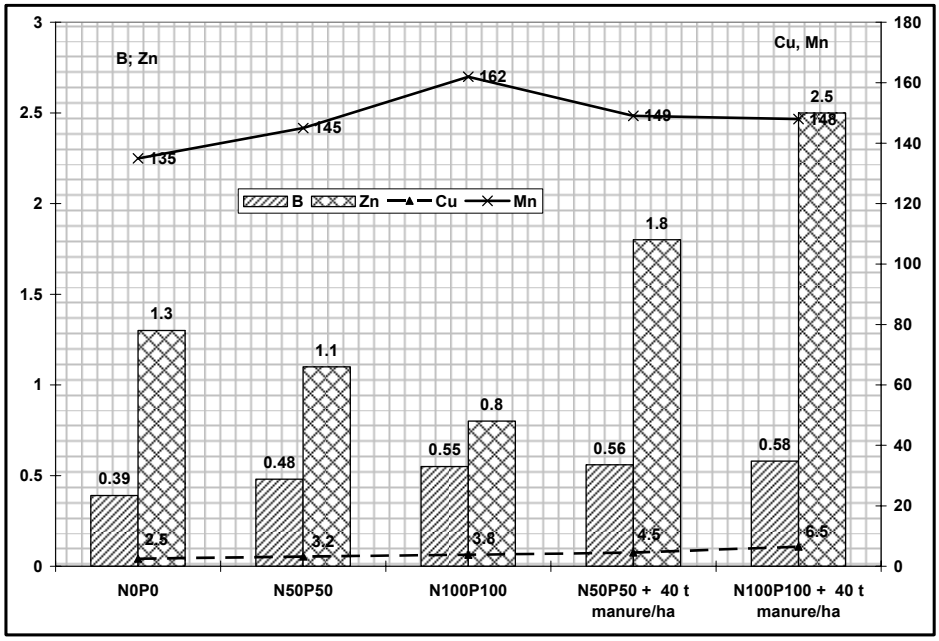

Fig. 1 - Microelement content from soil at different fertilization rates with nitrogen, phosphorus and manure

The mass of total carbon in Cambic Chernozem from the Moldavian Plain has registered significant increases at higher than $N_{50}P_{50}$ rates + 40 tmanure/ha (*Figure 2*). In wheat-maize rotation, very significant values of the carbon content were found only at organo-mineral fertilization ($N_{100}P_{100}$ + 40 t manure/ha).

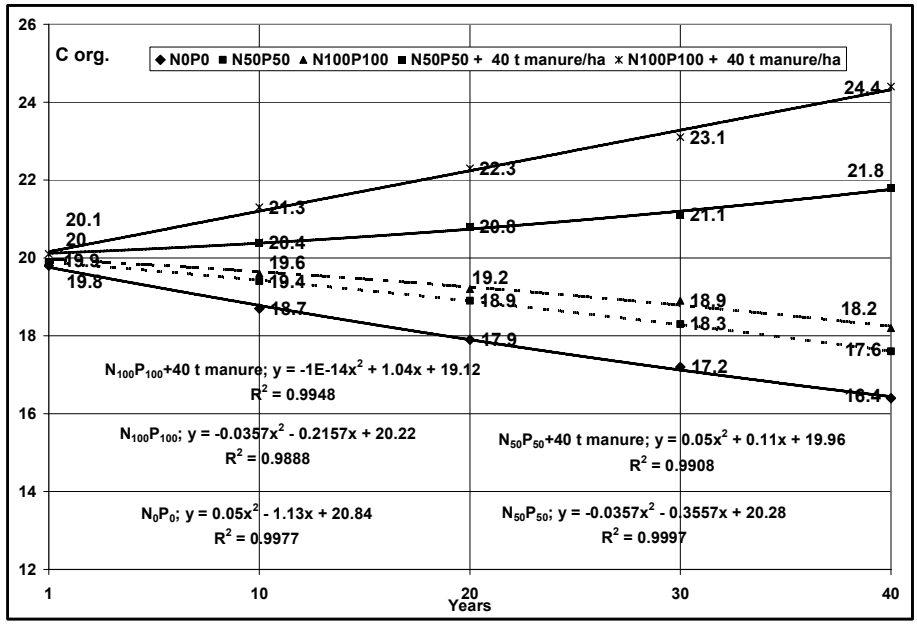

Fig. 2 - Influence of long-term fertilization on total organic carbon from soil (C, g/kg)

CONCLUSIONS

In wheat-maize crop rotation, applying mineral fertilizers during 1996-2007 resulted in getting mean yield increases, which varied according to rates, between 58 and 101% (874-1527 kg/ha) in wheat and between 52 and 96% (1404-2605 kg/ha) in 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 of 125% (1879 kg/ha) in wheat and 108% (2936 kg/ha) in maize.

The mean yield increases, obtained for each kg of a.i. of applied fertilizer, were comprised between 7.6 and 17.5 kg in wheat and between 13.0 and 28.1 kg in maize.

In the intensive rotations with cereals, with high annual consumption of nutrients, maintaining a good soil supply with humus and mineral elements is done only by organo-mineral fertilization ($N_{50}P_{50}$ or $N_{100}P_{100}$ + 40 t manure/ha).

In soils from the Moldavian Plateau, most of them situated on slope fields, poor in organic matter and nutrients, the proper use of different organic resources may replace a part of rich technological consumption (mineral nutrients), determine the improvement in the content of organic matter from soil and ensure better conditions for the capitalization of nitrogen fertilizers.

On the Cambic Chernozem from the Moldavian Plateau, a good supply with mobile phosphorus in wheat and maize crops (37-72 mg/kg) was done in case of the annual application of a rate of $N_{100}P_{100}$, while a very good supply (72-91 mg/kg) was achieved at the rate of $N_{50}P_{50}$+60 t/ha manure.

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