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EVOLUTION OF SOIL FERTILITY UNDER THE INFLUENCE OF ORGANIC FERTILIZERS AND EROSION ON SLOPE LANDS IN THE MOLDAVIAN PLAIN

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ABSTRACT - The influence of long-term fertilization on wheat and maize yield and soil fertility has been investigated at the Agricultural Research and Development Station of Podu-Iloaiei since 1968. The experiments have studied the influence of mineral fertilization, manure and crop residues on production, in peas-wheat-maize crop rotation and on soil fertility, on 16% slope field. Investigations were carried out on a typical Cambic Chernozem, which prevails in the Moldavian Plain and have established the fertilizer rates ensuring efficient yield increases and increasing the content of organic carbon from soil. The soil on which the experiments were set up have a clay-loam texture (420 g clay, 315 g loam and 265 g sand), a neuter to weakly acid response and a mean nutrient supply. On weakly eroded soils, the annual application of crop residues, which resulted from peas, wheat and maize crops, together with the rate of $N_{80}P_{60}$, have resulted in maintaining the content of organic content from soil at values of 18.8 g/kg soil. On highly eroded soils, the increase in the organic carbon content of soil from 18.8 to 21.6 g/kg soil was recorded by the long-term application of the rate of $N_{80}P_{60}$+60 t/ha manure. On 16% slope lands, the use of a crop structure made of 25% maize, 25% perennial grasses and legumes, 25% peas and 25 % wheat has determined the diminution by 62% of soil losses by erosion and the reduction by 61% of water runoff and mineral elements, compared to maize continuous cropping.

Key words: slope land, fertilizers, crop residue, manure, wheat, maize, organic carbon

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REZUMAT – Evoluția fertilității solului sub influența fertilizării organice şi a eroziunii pe terenurile în pantă din Câmpia Moldovei. Cercetările efectuate la S.C.D.A. Podu-Iloaiei, jud. Iaşi, au urmărit influența fertilizării cu îngrăşăminte minerale, gunoi şi resturi vegetale asupra producției, la culturile din asolamentul mazăre-grâu-porumb, şi asupra fertilității solului pe un teren cu panta de 16%. Studiile au fost efectuate pe un sol cernoziom cambic tipic, care predomină în Podişul Moldovei, şi au urmărit stabilirea dozelor de îngrăşăminte care asigură obținerea unor sporuri eficiente de producție, determinând menținerea sau creşterea conținutului de carbon organic din sol. Solul pe care au fost amplasate experiențele are o textură luto-argiloasă, o reacție neutră spre slab acidă şi o aprovizionare mijlocie în elemente nutritive. Pe terenurile slab erodate, aplicarea anuală a resturilor vegetale de la culturile de mazăre, grâu şi porumb, împreună cu doza de $N_{80}P_{60,}$ a determinat menținerea conținutului de carbon organic din sol la valori de 18.8 g/kg sol. Pe terenurile puternic erodate, creşterea conținutului de carbon organic din sol de la 18.8 la 21.6 g/kg sol s-a înregistrat prin aplicarea indelungată a dozei de N80P60+60 t/ha gunoi. Pe terenurile cu panta de 16%, folosirea unei structuri de culturi, care cuprinde 25% porumb, 25% leguminoase şi graminee perene, 25% mazăre şi 25 % grâu a determinat, comparativ cu monocultura de porumb, diminuarea pierderilor de sol prin eroziune cu 62% şi reducerea scurgerilor de apă şi elemente minerale cu 61%.

Cuvinte cheie: teren în pantă, fertilizare, resturi vegetale, gunoi, grâu, porumb, carbon organic

INTRODUCTION

The climatic conditions of the Moldavian Plain are characterized by a multiannual mean 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.

In the last period, the goal of many studies carried out in different countries 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 of greenhouse gases. (Ailincăi et al. 2009; Yadav et al., 2008; Rosner, 2008; Jităreanu et al., 2009).

The legislation proposed in September 2006 (Directive COM (2006) 232), by the amendment to the Directive 2004/35/EC, has as aim soil protection and conservation of soil capacity, in order to fulfil its economic, social, cultural and environment functions. The Directive COM (2006) 232 concerning soil protection in EU has identified the areas of erosion risk and organic matter decrease, as well as those affected by compaction and other degradation factors. The long-term experiments carried out at the Agricultural Research Station of Podu-Iloaiei, Iaşi County, have tried to establish some fertilization systems for getting efficient yield increases, which maintain or increase the content of organic carbon from soil. These trials were set up on a 16% slope field, with a Cambic Chernozem soil, which has a clayey loam texture, a neuter to weakly acid response and a mean supply in nutrients.

MATERIALS AND METHODS

The investigations concerning the influence of fertilizers on wheat and maize yield and soil erosion were carried out within some stationary experiments conducted since 1968. The experiments were conducted in a three year crop rotation (peas-wheat-maize). In wheat, we have used the Gabriela Variety, and in maize, the Oana Hybrid. After each cycle of crop rotation, chemical tests of soil samples were carried out in tested variants according to the well-known methods. The content of organic carbon was determined by the Walkley-Black method; to convert soil organic matter into soil organic carbon it was multiplied by 0.58. 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 extract of acetate-lactate (AL) at flame photometer. The determination of water runoff, soil and nutrients losses by erosion was done by means of plots for runoff control with the area of 100 m^2 and on the entire area of watershed, where experiments were set up by means of a hydrological station. This station contains a triangular spillway, pluviometer, pluviograph, limnograph and devices for sampling soil and water during rainfall. At raining, samples were taken for the determination of the partial turbidity and of the content of humus and mineral elements lost by erosion.

RESULTS AND DISCUSSION

The climatic conditions during 1997-2009 were favourable to maize growing and development in eight years and unfavourable, because of low rainfall amount, in the other five years. In the last 13 years, the deficit of rainfall recorded during April - August, as compared to the multiannual mean of the area, was between 25.1 and 106.3 mm in five years. The climatic conditions in the Moldavian Plain were characterized by the mean 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.

In all the countries, the quality of environment factors is affected by economic activities, climatic changes and water and soil pollution. Many studies carried out in different areas with different soil and climatic conditions have followed the establishment of the technological elements, which contributed to the increase of the organic carbon content from soil, diminution of soil erosion and of mineral element losses in the agricultural environment (*Table 1*)

During 1997-2009, the yield increases were the highest, from the economic point of view. In wheat, they were of 2022 kg/ha (106%), at a rate of N_{120}+80 P_2O_5 and 2846 kg/ha (149 %) when N_{80}+60 P_2O_5 +40 t/ha manure was used. On weakly eroded soil, the mean wheat yields obtained during 1997-2009 in wheat crop, placed in peas-wheat-maize rotation, were of 1906 kg/ha, under unfertilized, and of 422 kg/ha at high mineral fertilizer rates ($N_{160}P_{100}$) (*Figure 1*).

Table 1 – Investigations on the control of soil fertility in different countries

Authors	Ecological conditions	Treatment	Treatment effect
Russell A. E., 2006	Mollisol, Kanawha and Nashua, Iowa, USA	Nitrogen 0, 90, 180, 270 kg/ha	Increase of organic carbon content from soil at higher rates than 180 kg/ha nitrogen
Crecchio Carmine, 2008	Bari, Italia Fluvisol, sugar beet – wheat rotation	Sewage sludge 12 and 24 t/ha	Increase of organic carbon content from 13.3 to 15.0 g/kg soil and of total nitrogen from 1.55 to 1.65 g/kg soil
Hargreaves J.C., 2008	Loam Luvisol (42%) Dottikon and Rafz, Sweden	Sewage sludge 0.2 and 0.5 mg/kg dry soil	Soil contamination with Cd, Zn, Pb, Ni and Cu
Campbell C. A., 2005	Chernozem with ph 6.5, Saskatchewan, Canada	Wheat straw during 36 years	Nitrogen supply, 37 kg/ha/year
Morari F., 2008	Loam sandy soil Veneto, Italia (47% sand, 38% loam, 15% clay)	N, P_2O_5, K_2O 70, 70, 90 kg/ha and 140, 140, 180 kg/ha	Increase, after 40 years, of phosphorus content from soil, from 20.2 to 25.3 mg/kg of and potassium, from 50.0 to 64.5 mg/kg in sugar beet – soybean-wheat-maize rotation
Poulton P.R., 2006	Long-term trials from Rothamsted, England	N_{192} P_{35} K_{90} Mg_{35}	Increase of organic carbon content from soil at higher rates than $N_{192}P_{35}$ $K_{90}Mg_{35}$
Ulrich, S.A., 2006	Long-term trials from Halle, Germany, (37 years, Gleyic, sandy-loam Luvisol)	Conventional tillage with ploughing, chisel and no-tillage	Content of organic carbon increased from 10.0 g/kg (conventional system) to 13.2 g/kg at no-tillage
Blair Nelly, 2006	Long-term trials (Vertisol, 1966) from Wales, Australia	Cereals and alfalfa rotation	Increase of total carbon content from soil from 13.2 g/kg (wheat continuous cropping) to 18.22 g/kg at cereals-alfalfa rotation and increase by 45-126% of percent of hydrostable aggregates
Yadav Vineet, 2008	Long-term trials from Illinois,	Crop residues	Increase of organic carbon content from soil
Lindstrom M.J., 1986	Minnesota, USA	Soybean and maize residues (927 and 3706 kg/ha)	Decrease of eroded soil from 6.177 to 0.988 t/ha and reduction of water runoff from 35.6 to 22.9 mm

Authors	Ecological conditions	Treatment	Treatment effect
Linden D.R., 2000	Minnesota, USA	Soybean and maize residues (4942 and 9884 kg/ha)	Reduction of eroded soil by 85-98% and maize yield increase by 22%
Montanarella L., 2008	Soil Protection Framework Directive (SFD) (COM 232, 2006),	Farming technologies	In EU, over 150 million ha are affected by erosion and over 45% of soils have a low content of organic carbon
Rosner, J., 2008	Austria, during 1994-2007	Conservation tillage (direct drilling)	Decrease of soil losses from 6.1 to 1.8 t/ha/year, of nitrogen losses from 9.2 to 2.5 kg/ha/year and of phosphorus losses from 4.7 to 0.7 kg/ha/year
Franzluebbers Alan J. 2006	Mississippi, USA	Systems of soil conservation and crop residues	Reduction of soil losses by erosion from 18.0 (conventional system) to 3.0 t/ha/year
Totka Mitova, 2006	Bulgaria	Systems of soil conservation and crop residues	Reduction of soil erosion from 7.48 t/ha/year (maize) to 0.937 by minimum tillage and application of crop residues
Marchetti A., 2008	Abruzzo, Italia, (100 km^2)	Farming technologies	Organic carbon content from soil has low values on 87% of the area (1.62%), very low values (1.02%) on 6.4% of the area and mean values (2.08%) on 6.5% of the area
Dalgliesh N.P., 2007	Dalby, Australia clayey soils (60-75% clay)	Alfalfa in rotation with annual plants	Increase of carbon content from 0.96 to 1.26%

In wheat, the application of mean rates of mineral fertilizers with 60 t/ha manure has resulted in getting yield increases of 214% (2855 kg/ha), compared to the unfertilized variant (*Figure 2*). In wheat placed in 3 year crop rotation (peas-wheat-maize) after peas, the mean yield increases obtained for each kg of a. i. of applied fertilizer were between 10.1 and 10.9 kg grains, on weakly eroded soil and between 9.5 and 10.1 kg grains, on highly eroded soil.

On weakly eroded lands, the mean maize yields, obtained during 1997-2009, were comprised between 3284 kg/ha (100 %) at the unfertilized control and 7245 kg/ha (120 %), at rates of 80 kg N + 60 kg P_2O_5 + 60 t/ha manure (*Figure 3*).

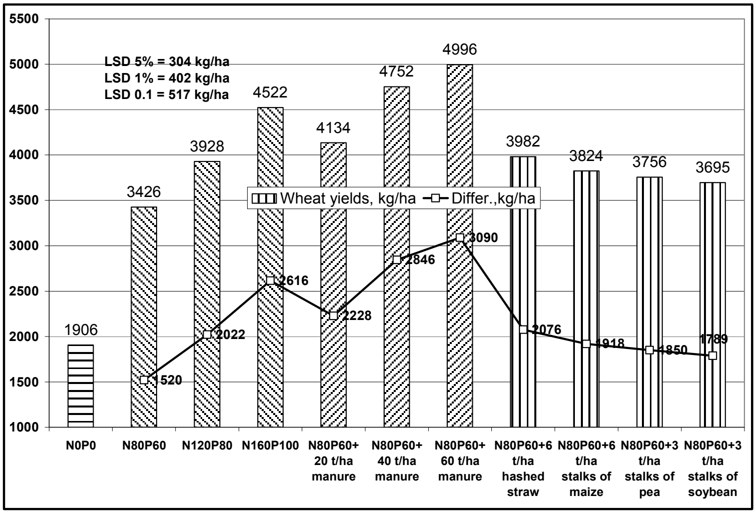


Fig. 1- Influence of mineral and organic fertilizers on wheat yields in weakly eroded soils, after 43 years of experiments

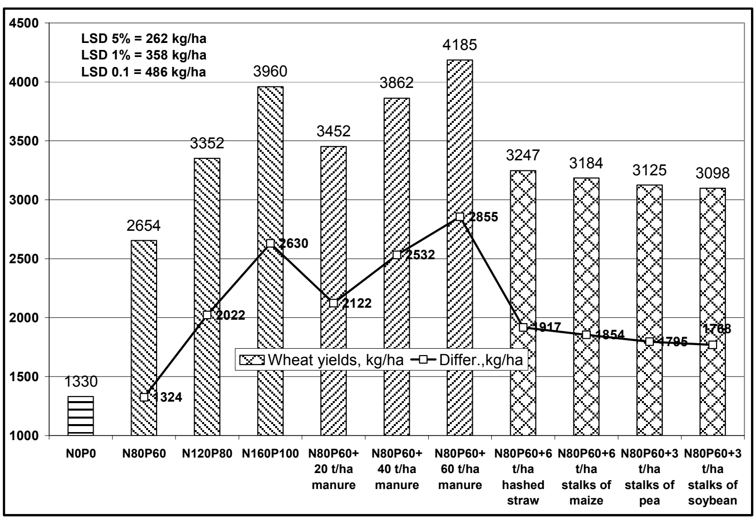


Fig. 2 - Influence of mineral and organic fertilizers on wheat yields in highly eroded soils

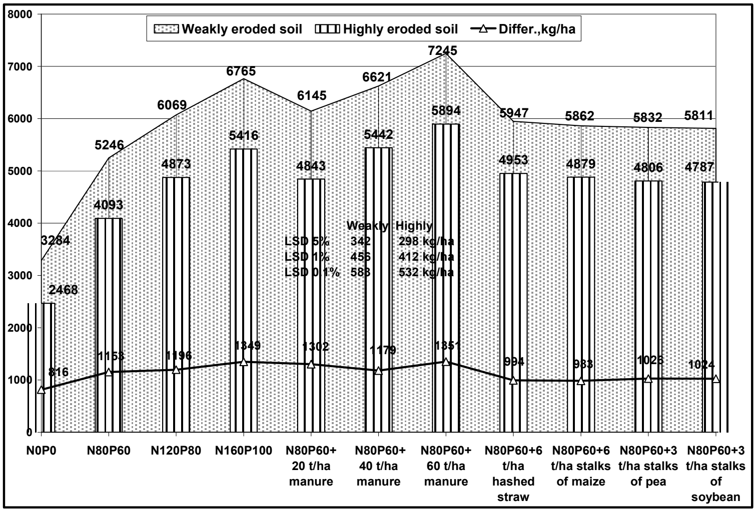


Fig. 3 - Mean maize yields obtained on slope lands with different erosion degrees, during 1997-2009 (Oana Hybrid)

On slope lands, the high rate fertilization of maize crop ($N_{160}P_{100}$) has determined, in the latest thirteen years, a mean yield increase of 105-119% (3481-2948 kg/ha) (on weakly and highly eroded soil), against the control. Applying a rate of $N_{80}P_{60}$+40 t/ha manure has resulted in getting a very close yield increase (102-120%, 3337-2974 kg/ha). The analysis of the obtained results has shown that the erosion process, by decreasing soil fertility, has determined the differentiation of mean wheat yields, according to slope and soil erosion, from 3902 (100%) to 3223 kg/ha (82.5%). The mean annual yield losses, caused by erosion, recorded in wheat in the last 13 years were of 679 kg/ha (17.4%) (*Figure 4*).

Because on slope lands, soil nutrient losses are very high, due to leaching, runoff and element fixing, establishing rates and time of fertilizer application must be done differentiate, according to soil characteristics, cultural practices and climatic conditions. The analysis of agro-chemical data shows that nitrogen fertilizers (ammonium nitrate) have determined the pH decrease. A significant diminution was recorded in the ploughed layer, at rates of 160 kg/ha N, where the pH value has reached 5.6, after 43 years (*Table 2*). The analyses carried out on the evolution of soil response, after 43 years of experiencing, have shown that the significant diminution in the pH value was found at higher rates than 120 kg N/ha. The lowest pH values were found in maize at rates of $N_{160}P_{100}$ and 80 kg N + 60 kg P_2O_5/ha + 6 t/ha stalks of maize, which can be explained by the unfavourable conditions in which the processes of nitrification and crop residue decay developed. After 43 years of testing, the pH value decreased, according to applied fertilizer rates, from 6.8 to 5.5, at a depth of 0-40 cm.

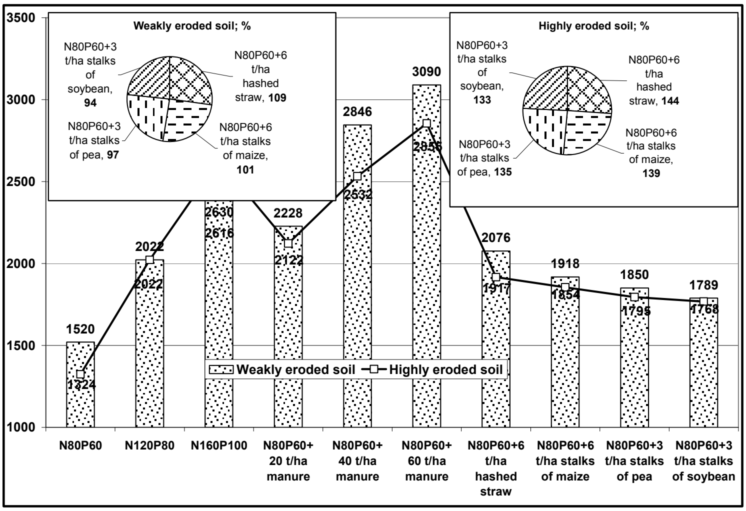


Fig. 4 – Mean yield increases (kg/ha and %) obtained in wheat on slope lands with different erosion degrees

The deterioration of structure and the decrease of pH and humus content resulted in the reduction of soil aeration and the available water reserve for plants. The obtained results demonstrated that on slope lands, the mineralization processes were stronger, in comparison with the humification ones, fact that required a more strict control of soil supply with nutritive elements. They changed rapidly under the influence of soil erosion and technological processes. Decomposition rates of the organic carbon from soil tended to increase once with higher soil temperature and moisture levels.

On the slope lands, poor in humus and mineral elements, the use of crop residues has a special importance for improving soil fertility indicators. The long-term use of crop residues has determined a better soil conservation by increasing organic matter and mineral element stock from soil, resulting in a decrease with time in the necessary of nitrogen and phosphorus fertilizers for crops.

The results of chemical analyses have shown that in the peas-wheat-maize rotation, by the annual application rate of $N_{120}P_{80}$, the decrease in the organic matter content from soil could not be prevented, its level increasing only at the variants where mineral fertilizers were applied with manure or crop residues. In this case, the values recorded in macronutrients have shown that soil supply was normal, compared to crop demands. Maintaining under favourable limits for plant growing and development of main soil chemical characteristics was done only in case of organo-mineral fertilization. On slightly eroded lands, maintaining a good supply in soil nutritive elements was done by the annual use of fertilizer rates of at least $N_{120}P_{80}$ or $N_{80}P_{60}$+ 40 t/ha manure, applied once in two years or $N_{80}P_{60}$ + 6 t/ha straw. On highly eroded lands, maintaining a good plant supply in mineral elements was done at rates of $N_{160}P_{100}K_{80}$ or $N_{80}P_{60}$ + 40 t/ha manure. Under these conditions, the organic carbon content from soil, after 43 years of experiencing, was maintained at the initial value and there were not found nutrition troubles with microelements in plants.

Table 2 - Effect of soil erosion and fertilization system on the organic carbon and mineral element content in 16% slope fields

Fertilizer rate	Weakly eroded lands				Highly eroded lands			
	pH (H_2O)	Org. C g/kg	P-AL (ppm)	K-AL (ppm)	pH (H_2O)	Org. C g/kg	P-AL (ppm)	K-AL (ppm)
N_0P_0	7.1	16.6	16.0	212	7.0	14.6	9	194
$N_{80}P_{60}$	6.8	17.0	52	186	6.7	14.8	42	174
$N_{120}P_{80}$	6.2	17.7	79	176	6.1	15.1	61	168
$N_{160}P_{100}$	5.6	18.2	87	171	5.5	16.5	67	154
60 t/ha manure	7.3	21.3	72	267	7.1	20.0	64	236
$N_{80}P_{60}$ + 60 t/ha manure	7.1	21.6	91	283	6.9	20.1	76	234
$N_{80}P_{60}$ + 6 t/ha hashed wheat	6.9	19.1	65	245	6.7	18.6	59	212
$N_{80}P_{60}$+6 t/ha stalks of maize	6.7	18.7	61	238	6.6	18.4	55	194
$N_{80}P_{60}$+3 t/ha stalks of peas	6.9	18.4	58	219	6.7	18.1	49	185
$N_{80}P_{60}$+3 t/ha stalks of soybean	6.8	18.4	54	224	6.6	18.1	48	183
Mean	**6.7**	**18.7**	**64**	**222**	**6.6**	**17.4**	**53**	**193**
LSD 5%	0.24	0.08	4.8	14.2	0.21	0.09	4.6	13.4
LSD 1%	0.35	0.11	7.2	22.1	0.32	0.12	6.7	19.7
LSD 0.1%	0.51	0.16	10.4	33.4	0.48	0.19	8.7	31.2

The annual application of rates of N_{160}+100 P_2O_5, in a three year crop rotation (peas-wheat-maize) has determined the accumulation of a reserve of mobile phosphates in soil of 67-78 mg kg^{-1}.

Because of the high potassium consumption from soil by wheat and maize, the content of mobile potassium from soil decreased until 154-171 mg/kg soil, when the rate of N_{160}+100 P_2O_5 was applied and increased until 234-283 at rates of 80 kg N + 60 kg P_2O_5 + 60 t/ha manure.

Many studies carried out in the last period have tried to establish some fertilizer rates, which could maintain or increase the content of organic carbon from soil and diminish gas emissions.

In peas-wheat-maize rotation, the mean rate fertilization with mineral fertilizers, together with 60 t/ha manure, has resulted in increasing the organic carbon content from 16.6 to 21.6 g/kg soil (*Figure 5*).

On the slope lands of the Moldavian Plain, the mean rate fertilization with mineral fertilizers (80 kg N + 60 kg P_2O_5/ha), together with 6 t/ha hashed wheat, has resulted in increasing the organic carbon content from 16.6 to 19.1 g/kg soil (15%). On weakly and highly eroded soil, the application of nitrogen and phosphorus fertilizers at high rates (120 kg N + 80 kg P_2O_5/ha) could not prevent the decrease in the organic carbon content from soil (*Figure 6*). In a three year crop rotation (peas-wheat-maize), the content of organic carbon from soil diminished by about 0.05-0.11 g/kg/year (on weakly and highly eroded soil) at the unfertilized variant, and by 0.03-0.08 g/kg/year at the rate of 120 kg N + 80 kg P_2O_5/ha. It increased by about 0.07 g/kg/year at the rate of 80 kg N + 60 kg P_2O_5/ha + 60 t/ha manure.

The results on water runoff and soil losses in different crops from the Moldavian Plateau, determined by control plots, have shown that, during 1986-2008, of the total amount of 560.7 mm rainfall, 357.9 mm (63.8%) produced runoff, which was between 6.2 mm in perennial grasses, on the second year of vegetation, and 28.4-29.7 mm, in maize and sunflower crops. The annual soil losses due to erosion, recorded at the same period, were between 0.298 t·ha^{-1} in perennial grasses, on the second year of vegetation, and 9.176 - 9.650 t·ha^{-1} in maize and sunflower crops.

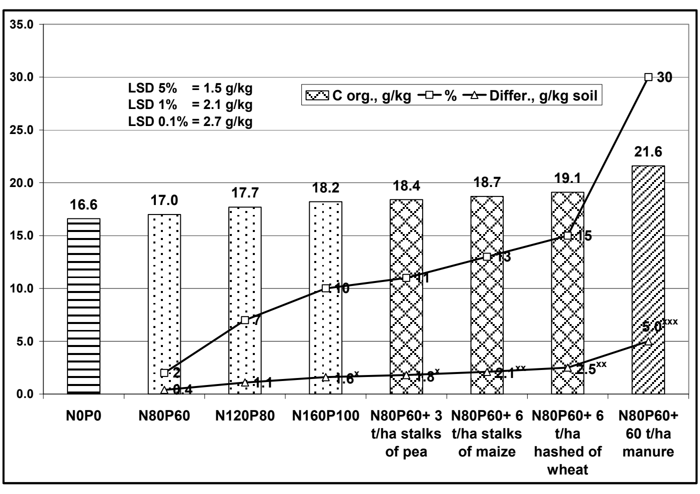


Fig. 5 -Organic carbon content from soil, after 42 years of applying different fertilizer rates

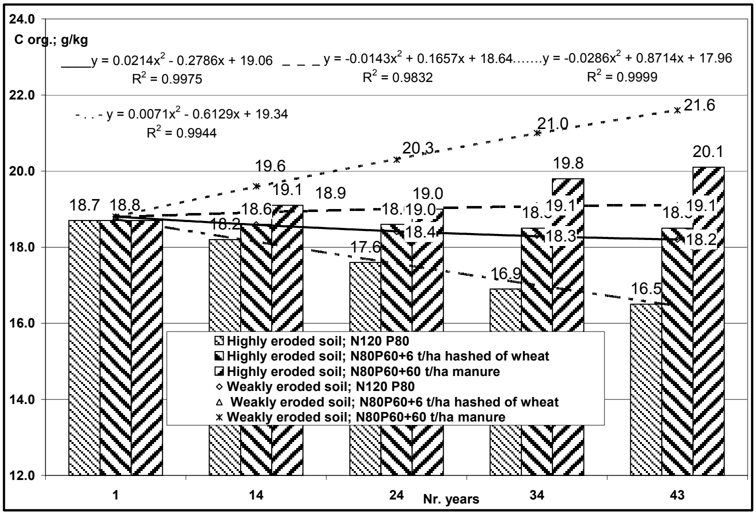
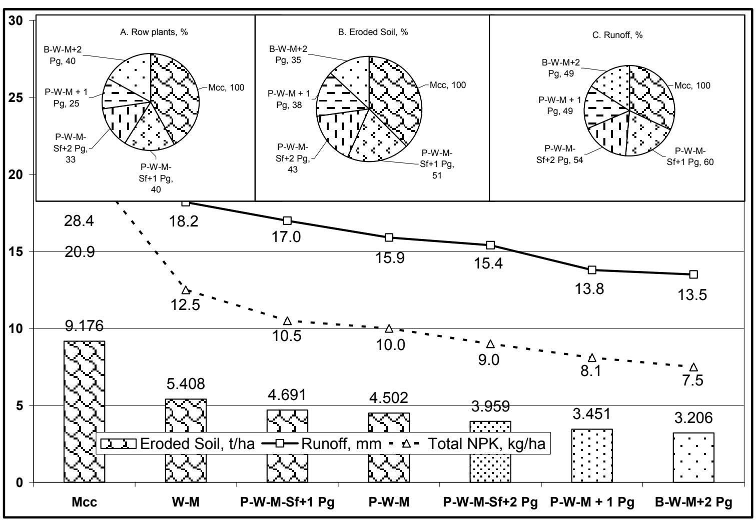


Fig. 6 - Change of organic carbon content from soil, after 43 years of applying different fertilizer rates



*Mcc= Maize continuous cropping; W= Wheat; B = Beans; P= Peas; M = Maize; Sf = Sunflower; Pg = Reserve fields cultivated with legumes and perennial grasses

Fig. 7 - Soil and mineral element losses by erosion in different crop rotations

From the investigations carried out on erosion, based on direct determinations, we found out that the effective erosion in the Moldavian Plateau, in peas-wheat-maize rotation, had a mean value of 4.502 $t \cdot ha^{-1} \cdot year^{-1}$ *(Figure 7)*. At 3- and 4-year crop rotations, which included good and very good cover plants for protecting soil against erosion, the amounts of eroded soil and nutrients lost by erosion were very close to the allowable limit for this area.

The obtained results on erosion in different crop rotations have shown that under conditions of 16% slope lands of the Moldavian Plateau, the diminution in soil losses below the allowable limit of 3-4 $t \cdot ha^{-1} \cdot year^{-1}$ was done only in 3-4 year crop rotations with one or two outside fields, cultivated with perennial grasses and legumes that protect better soil against erosion.

Erosion has affected soil fertility by removing, once with eroded soil, high amounts of humus and mineral elements, which reached 16-17 kg/ha nitrogen, 1-2 kg/ha phosphorus and 2-3 kg/ha potassium in maize and sunflower crops.

CONCLUSIONS

On highly eroded soils from the Moldavian Plain, the mean yields obtained during 1997-2009 were lower by 679 kg/ha (17.4%) in wheat and by 1124 kg/ha (19.1%) in maize, compared to the yields obtained on weakly eroded soils.

The long- term use of high nitrogen rates (N_{160}) has determined a pH decrease from 7.1 to 5.6.

On weakly eroded soils, the annual application of crop residues, which resulted from peas, wheat and maize crops, together with the rate of $N_{80}P_{60,}$ have determined maintaining the content of organic content from soil at values of 18.8 g/kg soil.

On highly eroded soils, the increase in the organic carbon content from soil from 18.8 to 21.6 g/kg soil was recorded by the long-term application of the rate of $N_{80}P_{60}$+60 t/ha manure.

On 16% slope lands, the use of a crop structure made of 25% maize, 25% perennial grasses and legumes, 25% peas and 25 % wheat has determined the diminution by 62% of soil losses by erosion and the reduction by 61% of water runoff and mineral element losses, compared to maize continuous cropping.

The crop structure, which determined the diminution in mean soil losses by erosion until 3.206 $t \cdot ha^{-1} \cdot year^{-1}$ included 20 % straw cereals, 20% annual legumes, 20% row crops and 40 % perennial grasses and legumes.

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