Cercetări Agronomice în Moldova
Vol. XLII , No. 1 (137) / 2009

EVALUATION OF THE LONG-TERM EFFECT OF CROP ROTATION ON WATER RUNOFF, SOIL AND NUTRIENT LOSSES IN THE MOLDAVIAN PLATEAU

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Received September 19, 2008

ABSTRACT - The goal of the experiments carried out during 1981-2008, at the Podu-Iloaiei Agricultural Research Station, Iaşi County, was the study of water runoff and soil losses, caused by erosion, in different crops, the annual rate of erosion processes under the influence of anti-erosion protection of different crops, the influence of water and soil erosion on the losses of organic matter and mineral elements from soil. On 16% slope fields, the use of peas - wheat – maize rotation + two outside fields, cultivated with perennial grasses, determined the diminution by 40.2% (1.291 t/ha) in the mean annual losses of eroded soil and by 36.7% (2.8 kg/ha) in nitrogen leakages, compared with wheat-maize rotation. The introduction of some rotations, which include in the crop structure 20% maize and plants for the protection against erosion (peas - wheat – maize rotation + two outside fields cultivated with perennial grasses) determined the diminution by 39.8% (24.7 kg/ha) in mean annual losses of organic carbon and by 37.5% (3.2 kg/ha) in losses of mineral elements. During 1981-2008, on 16% slope fields, the increase from 20 to 40% of the percent of row crops (maize and sunflower) used in rotations determined the increase in mean annual losses of eroded soil by 16.9% (0.325 t/ha) and the use of crop rotations with 60% row crops resulted in the increase by 78.9% (1.514 t/ha) of the mean annual quantities of eroded soil.

Key words: slope land, cropping systems, water erosion, organic carbon, nutrient losses, water quality

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REZUMAT - Evaluarea efectelor de lungă durată a rotaţiei culturilor asupra scurgerilor de apă, sol şi elemente minerale prin eroziune în Podişul Moldovei. Experienţele realizate la Staţiunea de Cercetare-Dezvoltare Agricolă Podu-Iloaiei, judeţul Iaşi, în perioada 1981-2008, au avut următoarele obiective: studiul scurgerilor de apă şi de sol prin eroziune, la diferite culturi, rata anuală a eroziunii, infuenţată de protecţia antierozională a diferitelor culturi, influenţa scurgerilor de apă şi a eroziunii solului asupra substanţei organice şi a elementelor minerale din sol. Pe terenurile cu panta de 16%, folosirea rotaţiei mazăre – grâu – porumb + două sole săritoare, cultivate cu ierburi perene a determinat, in perioada 1981-2008, reducerea pierderilor medii anuale de sol erodat, comparativ cu rotaţia grâu-porumb, cu 40.2% (1.291 t/ha) şi a scurgerilor de azot, cu 36.7% (2.8 kg/ha). Introducerea unor rotaţii care cuprind, în structura culturilor, 20% porumb, împreună cu plante bune si foarte bune protectoare împotriva eroziunii (mazăre – grâu – porumb + două sole săritoare, cultivate cu ierburi perene) a determinat, în perioada 1981-2008, comparativ cu rotaţia grâu-porumb, reducerea pierderilor medii anuale de carbon organic cu 39.8% (24.7 kg/ha) şi a pierderilor de elemente minerale cu 37.5% (3.2 kg/ha). In perioada 1981-2008, pe terenurile cu panta de 16%, creşterea procentului de plante prăşitoare (porumb şi floarea-soarelui) în rotaţii, de la 20 la 40%, a determinat creşterea pierderilor medii anuale de sol erodat cu 16.9% (0.325 t/ha), iar folosirea unor rotaţii cu 60% plante prăşitoare a determinat creşterea cantităţilor medii anuale de sol erodat cu 78.9% (1.514 t/ha).

Cuvinte cheie: teren în pantă, sisteme de cultură, eroziunea produsă de apă, carbon organic, scurgeri de elemente nutritive, calitatea apei

INTRODUCTION

In all the countries, the quality of environment factors is affected by economic activities, climatic changes and water and soil pollution.

The Soil Protection Framework Directive of EU includes the necessary legislative proposals, taken into account by all the Member States concerning the three main threats on the decline in organic matter, soil erosion and contamination and some additional aspects regarding compaction, diminution of biodiversity, salinisation, floods and landslides. In the EU, more than 150 million hectares of soil are affected by erosion and 45% of the European soils have a low content of organic matter (Montanarella, 2008). The aim of the normative regulations concerning the environment protection in EC, established by the Nitrate Directive, Sewage Sludge Directive, Pesticide Directive, Water Framework Directive, Biocide Directive and Habitat Directive, is to ameliorate the environment factors and, especially, the protection of water and soil resources. In this context, the goal of all the Member States is to follow the identification of all the activities with pollution risk on soil and water, the delimitation of contaminated areas and the establishment of national recovery strategies. For each identified area, which is affected by degradation factors, like soil erosion, organic matter decay, compaction, acidification, salinisation, etc., there are necessary some programmes of preventive measures, in order to eliminate the risk in these areas. In all the

countries, the investigations carried out in the last period have followed the establishment of some technological solutions that maintain the productivity of agroecosystem and the protection of environment factors.

As a result of the implementation of the EU Nitrate Directive (91/976/EC), aiming to prevent and reduce the nitrate water pollution, G. Palumbo found that in the two farming areas from Southern Italy (Campamarino and Venafro), having 45 km^2, on 59% of the studied area, the NO_3^- concentration had lower values than 36 mg/l and higher values than 100 mg/l on the rest of the area from Central Italy (Palumbo, 2008).

In Austria, during 1994-2007, the mean soil losses in three locations dropped from 6.1 t/ha/year to 1.8 t/ha/year, by using conservation tillage in cover crops, and until 1.0 t/ha/year with direct drilling. Nitrogen (9.2, 3.7, 2.5 kg/ha/year) and phosphorus (4.7, 1.3, 0.7 kg/ha/year) losses showed similar tendencies (Rosner et al., 2008).

The investigations conducted by Lazarov showed that the mean annual rate of erosion on the arable lands from Bulgaria was of 4.76 t/ha and of 2.69 t/ha on improved arable lands. Soil losses by erosion on the fields ploughed on the upstream-downstream direction, which are cultivated with maize, are of 7.48 t/ha. In sunflower, cultivated with conventional tillage, the annual eroded soil was of 3.044 t/ha, and by wheat straw and green fertilizer incorporation into soil, erosion has decreased at 2.327 t/ha and 0.937 t/ha, respectively (Mitova, 2006).

The investigations conducted on a Gray Luvisol in north-western Alberta, Canada, have shown that after 12 years, the content of organic carbon was highly influenced by the quantity of crop residues, which remained in soil from perennial grasses and legumes found in different crop rotations (Soon and Arshad, 2006).

The 12-year usage of red clover-wheat-canola-wheat crop rotation determined the increase in the content of organic carbon in soil from 17.9 g C kg^{-1} soil to 20.2 g C kg^{-1} soil, compared to peas-wheat-canola-wheat crop rotation. Under the same conditions, the content of total nitrogen from soil has increased from 1.31 g N kg^{-1} soil to 1.42 g N kg^{-1} soil. The studies carried out in the Teramo province (Abruzzo Region), where soil erosion is the main cause determining the diminution in the content of organic matter from soil, show that almost 87% of the total area has a low content in organic matter, comprised between 1.00 and 2.19% (on the average, 1.62%), 6.4% of the area has a very low content (ranging from 0.44 to 1.19%, on the average, 1.02%) and 6.5% of the area has a mean content (ranging from 1.81 to 2.87%, on the average, 2.08%) (Marchetti, 2008).

From the analyses carried out on the soils from the Teramo province, Italy (about 100 km^2), it resulted that on about 50% of the studied area, the C/N ratio had optimum values (soils with values between 9 and 12, with a stable and well humified organic matter), on 42% of the area, the C/N ratio had lower values than 9, which means that the oxidation processes prevail and soil organic matter is quickly decomposed. On 8% of the area, the C/N ratio is higher than 12,

indicating that soil nitrogen is insufficient for a good humification. The long-term trials, carried out since 1972 on the Fluvisol from Bari, Italy, with 39.7% loam, 33.4% clay and 26.9% sand, have shown that applying 100 kg/ha $N+P_2O_5+K_2O$ in beat- wheat - catch crop-wheat rotation (3 years) determined the increase in the content of organic carbon, nitrogen and phosphorus from soil and stimulated the enzyme activity from soil (Crecchio, 2008). Of the total Italian area, 51.8% is considered to be at potential risk of desertification. Soil erosion is the most relevant soil degradation system that affects at least 19% of the territory at the potential risk of desertification, while aridity is the second desertification risk (19.0%) (Constantini, 2008).

The main problems requiring agro-environment measures in Romania are the degradation degree of fields by erosion (6.3 million ha), deterioration of soil structure and compaction (on 44% of the total farming area). The primary compaction is found on 2 million ha of arable fields (13.59%), the tendency of crust formation at soil surface, on 2.3 million ha (15.63%) and soil chemical pollution, on 0.9 million ha.

Soil erosion affects the safety of dwellings, infrastructure and water quality in the affected areas (Source: Government of Romania - December 2005-National Plan of Development (NPD) 2007-2013, December 2005, National Agency of Cadastre and State Publicity, Statistical Yearbook of Romania, 2001, 2003, 2004).

The north-eastern region has 15.45% (2,131,421 ha) of the farming area of Romania (14,836, 585 ha) and includes very great areas with soils affected by erosion (over 60%), acidification, compaction, landslides and other degradation forms (Project of North-East Regional Development 2007-2013; Statistical Yearbook of Romania (2003).

MATERIALS AND METHODS

Investigations conducted during 1981-2008 on a Cambic Chernozem at the Agricultural Research and Development Station of Podu-Iloaiei, Iasi County, followed the influence of different crop rotations and fertilizers on water runoff and nutrient losses, due to soil erosion. Within the experiment, the following rotation scheme was followed: wheat and maize continuous cropping, 2-year crop rotation (wheat-maize), 3-year crop rotation (peas-wheat-maize) and 4-year crop rotation + outside field cultivated with legumes and perennial grasses (alfalfa + *Lolium* or Sainfoin + *Bromus*).

The determination of water runoff, soil and nutrient 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 the 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. When raining, samples are taken for the determination of the partial turbidity and of the content in humus and mineral elements lost by erosion. Experiments were conducted on the hydrographic basin of Scobălțeni, with a reception area of 159 ha, a mean altitude of 119.4 m, a mean slope of 11 % and a

mean slope length of 250 m. The area of the watershed has been anti-erosion set up since 1983, being used combined cropping systems made of sod rewetting and strip cultivation. The width of cultivated strips is 200-250 m on 5-10% slopes, 100-150 m on 10-15 % slopes and 50-100 m on 15-18 % slopes (*Figure 1*).

The content of total nitrogen, nitrates, phosphorus and potassium was determined on soil and water samples, lost by erosion, in different crops, thus establishing the losses of nutritive elements on the area of the watershed where experiments are placed. The content of organic carbon was determined by the Walkley-Black method, 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.

Fig. 1 – Geographic presentation of the Scobîlțeni - Iaşi watershed, set up with anti-erosion works, where the experimental devices were placed

RESULTS AND DISCUSSION

The climatic conditions in the Moldavian Plain were 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 28 years, the mean annual recorded quantity of rainfall was of 560.7 mm, of which 357.9 mm determined water runoff and soil losses by erosion.

On slope lands, soil nutrient losses being very high, due to leaching, runoff and element fixing, the establishment of rates and time of fertilizer application must be done differently, according to soil characteristics, cultural practices and climatic conditions. On eroded slope lands, the growing systems ensure the reduction in soil losses below the allowable limit of 3-4 t/ha/year and allow getting efficient yields from the economic point of view.

The results on water runoff and soil losses in different crops from the Moldavian Plateau, determined by control plots, have shown that, during 1981-2008, of the total amount of 560.7 mm rainfall, 357.9 mm (63.8%) produced water runoff, which was between 7.83 mm in perennial grasses, in the second year of vegetation, and 22.77-23.86 mm, in maize and sunflower crops (*Table 1*). The annual soil losses due to erosion, recorded at the same period, were between 0.164 t/ha in perennial grasses, in the second year of vegetation, and 5.770 – 6.605 t/ha in maize and sunflower crops. The obtained results on the potential erosion (conditioned by geo-morphological, soil and climate factors) have shown that on the fields uncovered by vegetation from the Moldavian Plateau, the mean soil losses due to erosion were of 18.4 t/ha/year, values corresponding to a moderate erosion risk. The protection degree of soil against erosion, expressed by the ratio between the value of the effective erosion (under specific technological conditions) and of the potential erosion (soil eroded under conditions of uncovered soil, which was not set up with soil erosion control works) is an indicator of erosion risk that shows soil vulnerability to erosion. It is given by the ratio between the value of the effective erosion and that of mean allowable erosion, which corresponds to soils from the studied watershed.

Table 1 - Mean annual runoff and soil losses due to erosion, recorded in different crops

Crop	Rainfall causing runoff (mm)	Runoff (mm)	Eroded Soil (t ha^{-1})	Runoff coefficient	Mean turbidity (g l^{-1})	Humus, (kg ha^{-1})
Field	357.9	44.26	12.869	0.12	29.1	431
Sunflower	357.9	23.86	6.605	0.07	27.7	221
Ist year perennial grasses	357.9	13.11	1.980	0.04	15.1	66
IInd year perennial grasses	324.5	7.83	0.164	0.02	2.1	5
Maize	357.9	22.77	5.770	0.06	25.3	194
Peas	357.9	13.34	1.940	0.04	14.5	65
Wheat	357.9	9.27	0.649	0.03	7.0	22
Beans	357.9	19.23	3.492	0.05	18.2	117
Mean annual rainfall, recorded during 1981-2008 = 560.7 mm						

Taking into account that the erosion process cannot be avoided and that the tolerance level of soil annual losses is 2-3 t/ha, which corresponds to the annual rate of soil renewal, the mean annual soil losses due to erosion, recorded during 1981-2008 in maize (5.770 t/ha) and sunflower (6.605 t/ha), may result in destructing the fertile soil layer in a few decades.

Erosion has affected soil fertility by removing once with eroded soil, high amounts of humus and mineral elements, which reached 12.28-13.04 kg/ha nitrogen, 0.65-0.76 kg/ha phosphorus and 1.44-1.62 kg/ha potassium, in maize and sunflower crops (*Table 2*).

On 16% slope lands, the mean annual nitrogen, phosphorus and potassium leaches, due to erosion, recorded during 1981-2008, were comprised between 9.088 and 15.416 kg/ha in row crops (beans and sunflower) and between 2.4 and 5.1 kg/ha/years in wheat and peas crops (*Table 2*). Data are very important for establishing and regulating the fertilizer rates applied in crops and for controlling the environment pollution with nitrogen, phosphorus and potassium.

Table 2 - Mean water runoff, soil, organic carbon and mineral element losses, due to erosion, in the Moldavian Plateau

Crop	Runoff (mm)	Eroded soil (t/ha)	Organic carbon and mineral elements lost by erosion, kg/ha						
			Organic carbon	N_t in runoff	N_t in eroded soil	Total N	P-AL	K-AL	Total NPK
Field	44.3	12.869	250.0	3.948	18.403	22.351	1.480	3.089	26.919
Sunflower	23.9	6.605	128.3	3.197	9.841	13.039	0.760	1.618	15.416
Ist year perennial grasses	13.1	1.980	38.2	1.481	2.930	4.412	0.228	0.493	5.133
IInd year perennial grasses	7.8	0.164	3.2	0.885	0.256	1.141	0.018	0.041	1.200
Maize	22.8	5.770	112.4	3.393	8.886	12.279	0.646	1.443	14.367
Peas	13.3	1.940	37.8	1.668	2.891	4.558	0.177	0.388	5.123
Wheat	9.3	0.649	12.6	1.224	1.019	2.243	0.073	0.162	2.478
Beans	19.2	3.492	68.1	2.596	5.482	8.078	0.311	0.698	9.088

On 16% slope lands, the mean annual losses of nitrogen due to erosion were comprised, during 1981-2008, between 12.3 kg/ha in maize continuous cropping and 4.599 kg/ha/year in peas - wheat – maize rotation + two outside fields cultivated with perennial grasses (*Table 3*). If phosphorus and potassium losses are low (0.76-1.6 kg/ha/year), the nitrogen losses should be diminished by using rotations with crop structures that protect soil against erosion.

Table 3 - Mean annual losses of nitrogen due to erosion in different crops rotation

Crop rotation	N_t in runoff water		N_t in runoff water and eroded soil		Row plants, %
	kg ha^{-1}	%	kg ha^{-1}	%	
Maize continuous cropping	3.393	100	12.279	100	100
Beans - wheat –sunflower – maize- wheat rotation	2.327	69	7.576	62	60
Wheat-maize rotation	2.309	68	7.261	59	50
Peas - wheat – maize – sunflower rotation + an outside field cultivated with perennial grasses	2.103	62	6.815	56	40
Peas - wheat – maize rotation	2.095	62	6.350	52	33
Peas - wheat – maize – sunflower rotation + two outside fields cultivated with perennial grasses	1.925	57	6.006	49	33
Beans - wheat -maize rotation + two outside fields cultivated with perennial grasses	1.856	55	5.303	43	40
Peas - wheat – maize rotation + an outside field cultivated with perennial grasses	1.830	54	5.260	43	25
Peas - wheat – maize rotation + two outside fields cultivated with perennial grasses	1.671	49	4.599	37	20

From the investigations carried out on effective 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 2.786 t/ha/year (*Table 4*). 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 from the Moldavian Plateau, the diminution in soil losses below the allowable limit of 3-4 t/ha/year 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.

These elements were necessary for establishing the crop structure and dimensioning the anti- erosion works, which determined the diminution of soil erosion and water runoff, soil and nutrient losses below the limit corresponding to the natural capacity of annual soil recovery, of 3-4 t/ha/year of eroded soil.

The results concerning water runoff, soil and mineral element losses from crops, placed in different rotations, have shown that on 16% slope lands, the use of peas-wheat-maize rotation + 2 outside fields, cultivated with legumes and perennial grasses, resulted in soil losses, which diminished by 40.2 %, as compared to wheat-maize rotation (*Table 4*).

Table 4 - Mean annual losses of soil and nutritive elements in different crops rotations

Crop rotation	Eroded Soil		Total NPK in water runoff and eroded soil		Row plants, %
	kg ha^{-1}	%	kg ha^{-1}	%	
Maize continuous cropping	5770	100	14.367	100	100
Beans - wheat –sunflower – maize- wheat rotation	3433	59	8.765	61	60
Wheat-maize rotation	3210	56	8.423	59	50
Peas - wheat – maize – sunflower rotation + an outside field cultivated with perennial grasses	3116	54	7.913	55	40
Peas - wheat – maize rotation	2786	48	7.323	51	33
Peas - wheat – maize – sunflower rotation + two outside fields cultivated with perennial grasses	2700	47	6.958	48	33
Beans - wheat -maize rotation + two outside fields cultivated with perennial grasses	2244	39	6.060	42	40
Peas - wheat – maize rotation + an outside field cultivated with perennial grasses	2229	39	6.038	42	25
Peas - wheat – maize rotation + two outside fields cultivated with perennial grasses	1919	33	5.267	37	20

During 1981-2008, the use of crop rotations with a percent until 20% of row plants, which also included outside fields cultivated with perennial grasses, has determined the diminution in soil and mineral element losses by 40.2% and, respectively, 37.4%, as compared to 2-year crop rotation (wheat-maize). According to these results concerning the contribution of melioration plants to the diminution of soil and mineral element losses due to erosion, the technical elements were established for anti-erosion works, such as width of cultivated strips and of sod rewetting, crop structure, crop rotations and assortment of legumes and perennial grasses used on slope lands.

This scientific information is a source of creating a database necessary to the elaboration of land improvement projects, to watershed setting up and grounding the methods of protecting soil and water resources.

CONCLUSIONS

Mean annual losses of soil by erosion, recorded during 1981-2008, were of 0.164 t/ha in perennial grasses in the second growth year, 3.492 t/ha in beans, 5.770 t/ha in maize and 6.605 t/ha in sunflower.

Mean annual losses of nitrogen caused by erosion, recorded during 1981-2008, were of 1.141 kg/ha in perennial grasses in the second vegetation year, 8.078 kg/ha in beans, 12.279 kg/ha in maize and 13.039 kg/ha in sunflower.

Erosion affects soil fertility by removing together with eroded soil, significant humus and mineral element amounts, which in maize and sunflower crops reach 12.3-13.1 kg/ha nitrogen, 0.65-0.76 kg/ha phosphorus and 1.4-1.6 kg/ha potassium, representing, on the average, 10-12% of the chemical fertilizers necessary for these crops.

The highest losses of nutrients were recorded in 2-year rotation (wheat-maize) (7.26 kg/ha nitrogen and 8.42 kg/ha total NPK). These amounts decreased very much at the same time with the increase in the rotation structure of cover crops, such as peas, wheat, alfalfa and perennial grasses.

On 16% slope lands, the crop structure, which determined, during 1981-2008, the diminution in mean soil losses by erosion until 1.919 t/ha/year included 20% straw cereals, 20% annual legumes, 20% row crops and 40% perennial grasses and legumes.

On 16% slope fields, the use of peas - wheat – maize rotation + two outside fields, cultivated with perennial grasses, determined the diminution by 40.2% (1.291 t/ha) in the mean annual losses of eroded soil and by 36.7% (2.8 kg/ha) in nitrogen leakages, compared with wheat-maize rotation.

The introduction of some rotations, which include in the crop structure 20% maize and plants for the protection against erosion (peas - wheat – maize rotation + two outside fields cultivated with perennial grasses) determined the diminution by 39.8% (24.7 kg/ha) in mean annual losses of organic carbon and by 37.5% (3.2 kg/ha) in losses of mineral elements.

During 1981-2008, on 16% slope fields, the increase from 20 to 40% of the percent of row crops (maize and sunflower) used in rotations determined the increase in mean annual losses of eroded soil by 16.9% (0.325 t/ha) and the use of crop rotations with 60% row crops resulted in the increase by 78.9% (1.514 t/ha) of the mean annual quantities of eroded soil.

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