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THE IMPACT OF LONG-TERM FERTILIZATION AND IRRIGATION ON WHEAT AND MAIZE YIELD ON SLOPE LANDS IN THE MOLDAVIAN PLAIN

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ABSTRACT - The influence of long-term fertilization and irrigation on wheat and maize yield and soil fertility was studied at the Agricultural Research and Development Station of Podu-Iloaiei since 1980. These experiments were carried out on a 10 % slope field, on a Cambic Chernozem with clayey loam texture (423 g clay, 315 g loam and 262 g sand), a neuter to weakly acid reaction and a mean nutrient supply. The mean annual rainfall amounts, recorded in the last 28 years, were higher, with values comprised between 12.7 and 279.2 mm, compared to the multiannual mean on 80 years (542 mm) in 16 years, and lower by 25.3 - 236.7 mm in 10 years. Annual application of rates of N_{160} P_{80}, in a four-year crop rotation (soybean-wheat-sugar beet-maize) + a reserve field, cultivated with legumes and perennial grasses, determined the accumulation of a reserve of mobile phosphates of 78 mg/kg soil. Under irrigated, a good plant supply with mineral elements and the increase in the content of organic carbon from soil were done by applying the rate of $N_{80}P_{70}$+ 30 t/ha manure. Nitrogen and phosphorus fertilizers, although applied at high rates (N_{130} +100 P_2O_5), could not prevent the decrease in organic carbon content from soil.

Key words: slope field, deficit irrigation, fertilization, wheat, maize, organic carbon

REZUMAT – Impactul irigației şi al fertilizării pe termen lung asupra producției de grău şi porumb, pe terenul în pantă din Câmpia Moldovei. Influența irigației şi a fertilizării pe termen lung asupra producției de grâu şi porumb a fost studiată la Stațiunea de Cercetare-Dezvoltare Podu-Iloaiei din 1980. Experiențele au fost realizate pe un teren cu panta de 10 %, pe un sol cambic cernoziom cu textură luto-argiloasă (423 g argilă, 315 g lut şi 262 g nisip), o reacție neutră spre slab acidă şi un nivel mediu de aprovizionare. Cantitățile medii anuale de precipitații, înregistrate în ultimii 28 de ani, au fost mai mari timp de 16 ani, având valori cuprinse între 12.7 şi 279.2 mm, în comparație cu media multianuală pe 80 de ani (542 mm), şi mai scăzute, cu valori cuprinse între 25.3 şi 236.7 mm, timp de 10 ani. Aplicarea

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anuală a dozei de N_{160} P_{80}, într-o rotaţie de 4 ani (soia-grâu–sfeclă de zahăr-porumb) + o solă săritoare, cultivată cu leguminoase şi ierburi perene, a determinat acumularea în sol a unei rezerve de fosfaţi mobili de 78 mg/kg sol. În condiţii de irigare, s-au realizat o bună aprovizionare a plantelor cu elemente minerale şi creşterea conţinutului de carbon organic din sol, prin aplicarea dozei de $N_{80}P_{70}$+ 30 t/ha îngrăşământ natural. Deşi aplicate în doze mari (N_{130} +100 P_2O_5), îngrăşămintele cu azot şi fosfor nu au putut împiedica scăderea conţinutului de carbon organic din sol.

Cuvinte cheie: teren în pantă, irigare în deficit, fertilizare, grâu, porumb, carbon organic

INTRODUCTION

The dry climate in the Moldavian Plain, also increased by high torrential rainfall, requires the use of all the methods, which preserve water from soil and irrigation. The study of multi-annual climatic data showed that draught could last 28 days once in two years, 42 days once in ten years and 48 days in five cases of one hundred. 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. Because the average deficit of rainfall in the unirrigated area varies between 76 mm and 174 mm, the achievement of the best regime of soil moisture must have in view all the factors, which act as a whole in the soil-plant-air system.

In the last period, the goal of many studies carried out in different countries was to improve the technological elements concerning soil fertilization, tillage, irrigation and crop rotations with perennial grasses and legumes, which determine the increase in the content of organic carbon from soil, the diminution of soil erosion and the effect of greenhouse gases (Ailincăi et al., 2007; Yadav et al., 2008).

The efficient use of water resources depends on new irrigation techniques, sprinkler and drip irrigation systems and irrigation programmes with deficit irrigation.

In order to establish the technological elements for plant growing (fertilization, soil tillage, etc.), under conditions of deficit irrigation, we must know the crop response to water stress in certain vegetation periods and soil characteristics. The investigations carried out on the influence of water stress at specific growth stages of soybean, maize, sugar beet, wheat and barley on yield have shown that exposing crops to water stress may not cause significant yield decreases.

Irrigation and new agricultural production methods can play an important role in the development of agricultural sectors in Europe. In 2000, Italy had the highest irrigated area (3.9 million ha), followed by Spain (3.5 million ha) (Campling et al., 2003). The substantial expansion of the irrigated area in France and Spain was influenced by policy measures supporting the provision of irrigation infrastructure and providing subsidies for farmers for installing irrigation equipment, as well as guaranteeing low water prices for agriculture (Campling et al., 2003).

On the irrigated sandy-clayey fields from the experimental farm of the Instituto de Recursos Naturales y Agrobiologia de Sevilla, Spain, the nitrate leaching during the entire experimental period (1991-1993), under an irrigated maize crop, amounted to 150 and 43 kg ha^{-1} in the treatment with high (510 kg N $ha^{-1}y^{-1}$) and low (170 kg N $ha^{-1}yr^{-1}$) nitrogen fertilization, respectively (Moreno, 1999).

MATERIALS AND METHODS

The investigations on the influence of fertilizers and irrigation on wheat and maize yield and soil erosion was carried out within some stationary experiments since 1980. The experiments were carried out on a cambic chernozem with a slope of 10%, found in a southern position. The soil has a humus content of 2.9- 3.28%, a neutral reaction and a good mobile phosphorus (39-66 ppm) and potassium (198-258 ppm) supply. The assignment of the irrigation regime was done according to the method of water balance from soil during the growing period of the irrigated crops. Thus, watering time and number were assigned according to soil moisture, climatic conditions and requirements of grown genotypes. The experiment was conducted according to the experimental scheme, to the method of blocks, on uniform land, as concerns soil fertility, relief, predecessor plant and used technology.

In order to save water and power, irrigation rates were limited to 400 and 600 m^3/ha, respectively, and applied differently, according to weather, soil moisture and needs of grown genotypes. In wheat, we have used Fundulea 4 (1980-2002) and Gabriela varieties since 2003, and in maize, Podu-Iloaiei - 110 (1980-1999) and Oana hybrids, since 2000.

The experiments were conducted in a four-year crop rotation (soybean-wheat-sugar beet-maize) + a reserve field, cultivated with legumes and perennial grasses, which fallow once in four years.

After each cycle of crop rotation, physical, chemical and biological tests of soil samples were carried out in the 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 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.

RESULTS AND DISCUSSION

The climatic conditions in the Moldavian Plain were characterized by a multiannual mean temperature of 9.6°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.

The research carried out at the Podu-Iloaiei Agricultural Research Station, Iaşi County, during 1980-2008, had in view the influence of different watering and fertilizer rates on yield and soil fertility. During 1980-2008, 44 watering rates were applied in winter wheat (two of them were applied on 23 April, 11 May and in June; in 8 years, wheat was irrigated in autumn, too, for assuring the emergence). A number of 49 watering rates were used in maize, of which nine were applied on 17 May, 11 June, in July and 12 in August. The results concerning the intensity and uniformity of spreading water by sprinkler irrigation on lands with a slope of 8-10% pointed out that by using the ASJ – 1M sprinklers in watering schemes of 18x18 and by ensuring a working pressure of 2.8-3.4 kgf/cm^2 to the sprinkler, the uniformity coefficient (UC) varied between 74.9 and 81.5 %, according to wind speed (which did not exceed 2.5 m/s). Ensuring these quality indices at watering and limiting them to 400 mm during the first growth stages and to 600 mm at critical stages, compared to crop water requirements (flowering-grain formation and filling), 8-10% slope lands can be successfully irrigated without increasing the erosion process. The analyses carried out on runoff water on irrigated slope lands showed that the total nitrogen content from runoff water varied between 8.12 and 14.82 mg/l, according to crop and applied fertilizers.

Under conditions of 60% of the arable land of the country (3.5 mil. ha), the lands having slopes higher than 5% and rainfall not uniformly spread during the growing period, the yield increase should be achieved by irrigation and soil fertility improvement.

The mean wheat yield, obtained at different fertilizer rates, during 1980-2008, under unirrigated, was of 320 kg/ha, and it has increased until 4569 and 4861 kg/ha, respectively (30-38%), by applying watering rates of 400 and 600 m^3/ha (*Table 1*). The highest yield increases from the economic point of view, obtained in wheat during 1980-2008, were of 2228 kg/ha (89%) at a rate of N_{120}+100 P_2O_5 and 2685 kg/ha (107 %) when N_{80}+70 P_2O_5 +30 t/ha manure was used.

In maize crop, the use of watering rates of 400 and 600 m^3/ha has resulted in getting mean yield increases of 23 and 30%, respectively, (1377-1738 kg/ha) during 1980-2008 (*Table 2*). Mean yield increases in maize, due to fertilizers, varied between 1929 and 3759 kg/ha (56-110%), under unirrigated, and between 2326 - 4553 kg/ha (54-100%), under irrigated, according to applied rates.

In wheat grown in 5-year crop rotation after soybean, under irrigated, mean yield increases obtained for each kg a. i. of applied fertilizer were between 10.6 and 10.9 kg grains (*Table 3*).

In maize crop, the use of watering rates of 400 and 600 m^3/ha has resulted in getting mean yield increases obtained for each kg a. i. of applied fertilizer, between 16.2 and

17.0 kg grains (*Table 3*). Crop irrigation determines a better valorisation of fertilizers. Mean multiannual yield increases for each kg of applied fertilizer have augmented from 8.8 to 10.9 kg grains in wheat and from 3.5 to 17 kg in maize, compared to unirrigated. The mean multiannual yield increases, obtained under irrigated, were comprised between 22.4 and 26.2 kg grains at 10 m^3 water per ha in wheat and between 29.0 and 34.4 kg grains at 10 m^3 water per ha in maize, according to applied fertilizer rates (*Table 4*).

Table 1- Influence of irrigation regime and fertilizers on wheat yield

Fertilizer rate	Unirrigated			Irrigated 40 mm			Irrigated 60 mm		
	Yield		Dif.	Yield		Dif.	Yield		Dif.
	kg/ha	%		kg/ha	%		kg/ha	%	
N_0+0 P_2O_5	1944	100		2683	100		2907	100	
N_{80}+70 P_2O_5	3316	171	1372	4330	161	1647	4649	160	1742
N_{120}+100 P_2O_5	3857	198	1913	5025	187	2342	5335	184	2428
N_{160}+100 P_2O_5	4171	215	2227	5326	199	2643	5614	193	2707
N_{80}+70 P_2O_5+30 t/ha manure	4311	222	2367	5480	204	2797	5798	199	2891
Mean	3520	100	-	4569	130	1049	4861	138	1341
LSD 5%			309	LSD 1%		424	LSD 0.1%		584

Table 2 - Influence of irrigation regime and fertilizers on maize yield

Fertilizer rate	Unirrigated			Irrigated 40 mm			Irrigated 60 mm		
	Yield		Dif.	Yield		Dif.	Yield		Dif.
	kg/ha	%		kg/ha	%		kg/ha	%	
N_0+0 P_2O_5	3431	100		4339	100		4560	100	
N_{80}+70 P_2O_5	5360	156	1929	6665	154	2326	7057	155	2497
N_{120}+100 P_2O_5	6499	189	3068	7984	184	3645	8404	184	3844
N_{160}+100 P_2O_5	6922	202	3491	8522	196	4183	8956	196	4396
N_{80}+70 P_2O_5+30 t/ha manure	7190	210	3759	8773	202	4434	9113	200	4553
Mean	5880	100	-	7257	123	1377	7613	130	1738
LSD 5%			377	LSD 1%		527	LSD 0.1%		728

Table 3 – Mean yield increase obtained at different fertilizer rates and watering rates (kg grains per kg a.i. fertilizer)

Fertilizer rate	Wheat			Maize		
	Unirrigated	Irrigated 40 mm	Irrigated 60 mm	Unirrigated	Irrigated 40 mm	Irrigated 60 mm
N_{80}+70 P_2O_5	9.1	11.0	11.6	12.9	15.5	16.6
N_{120}+100 P_2O_5	8.7	10.6	11.0	13.9	16.6	17.5
N_{160}+100 P_2O_5	8.6	10.2	10.4	13.4	16.1	16.9
N_{80}+70P_2O_5+30 t/ha manure	8.8	10.4	10.7	13.9	16.4	16.9
Mean	**8.8**	**10.6**	**10.9**	**13.5**	**16.2**	**17.0**

Table 4 – Mean yield increases obtained at different fertilizer rates and watering rates (kg grains at 10 m^3 water/ha)

Fertilizer rate	Wheat		Maize	
	Irrigated 40 mm	Irrigated 60 mm	Irrigated 40 mm	Irrigated 60 mm
N_0+0 P_2O_5	18.5	16.1	22.7	18.8
N_{80}+70 P_2O_5	25.4	22.2	32.6	28.3
N_{120}+100 P_2O_5	29.2	24.6	37.1	31.8
N_{160}+100 P_2O_5	28.9	24.1	40.0	33.9
N_{80}+70 P_2O_5+30 t/ha manure	29.2	24.8	39.6	32.1
Mean	**26.2**	**22.4**	**34.4**	**29.0**

Appling water during the plant critical growth and development stages (flowering, grain formation and filling) has increased the efficiency of using deficit irrigation. This practice, although requiring a diminution in a part of production, resulted in the reduction of water and power costs, which were higher than the crop profit.

The obtained results made us assess that on irrigated slope lands they might obtain similar yields to those obtained on plane lands, if the technological processes and technical elements of the irrigation regime were correctly managed.

The analyses carried out on soil samples from the profile, under irrigated, showed some changes of the chemical characteristics. After 28 years of testing, the pH value decreased, according to applied fertilizer rates, from 7.8 to 5.5 - 6.7, at a depth of 0-40 cm (*Figure 1*). The deterioration of soil texture and the decrease of pH and humus content resulted in the reduction of soil aeration and available water for plants. The obtained results have shown that on slope lands, under irrigated, the mineralization processes were stronger, in comparison with the humification ones, fact that required a more strict control of the soil supply with nutritive elements; they changed rapidly under the influence of soil erosion and technological processes. The decomposition rates of soil organic carbon tended to increase once with higher soil temperature and moisture levels (Bolinder et al., 2007). Annual application of rates of N_{160}+100 P_2O_5 has resulted in the diminution of the response of soil, which was cultivated during 28 years under irrigated, at different fertilizer rates, from 7.8 to 5.5, showing a weak to mean soil acidity (*Figure 1*).

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

In soybean-wheat-sugar beet-maize rotation + a reserve field, cultivated with legumes and perennial grasses, under irrigated, the mineral fertilization with high fertilizer rates ($N_{160}P_{100}$) has determined the diminution in the content of soil organic carbon from 19.4 to 16.9 g/kg soil. The mean rate fertilization with mineral fertilizers ($N_{80}P_{70}$), together with 30 t/ha manure, has resulted in increasing organic carbon content from 19.4 to 20.6 g/kg, under irrigated (*Figure 2*).

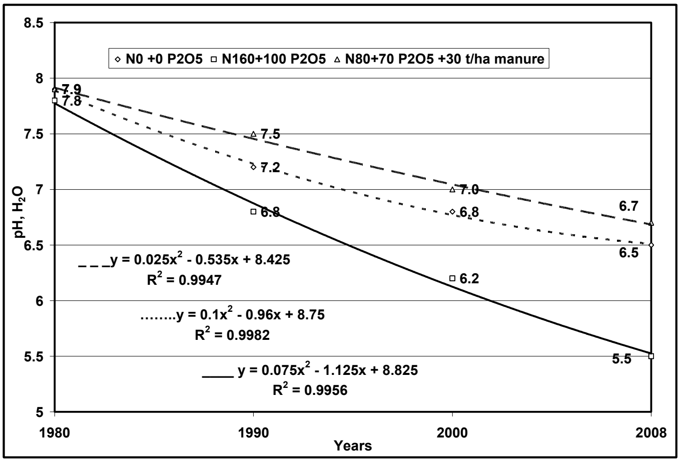

Fig. 1- Change of soil response, influenced by different fertilizer rates, after 28 years of experimentation

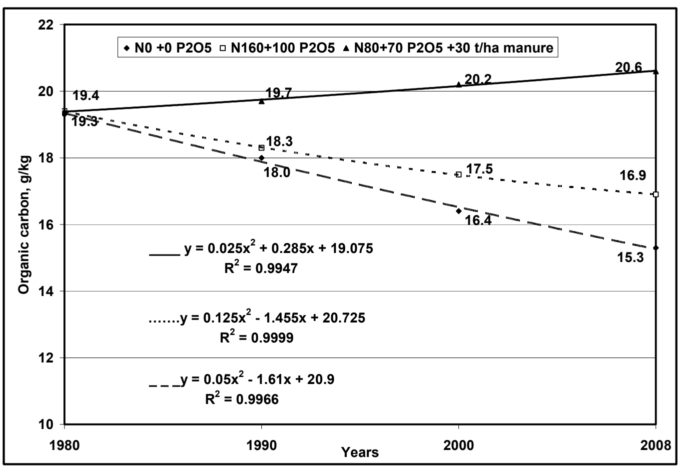

Fig. 2 - Organic carbon content after 28 years of applying different fertilizer rates, under irrigated

Under irrigated, the content of organic carbon from soil diminished by about 1.61 g/kg/year at the unfertilized variant and by 1.45 g/kg/year at the rate of $N_{160}P_{100}$ and increased by about 0.29 g/kg/year at the rate of $N_{80}P_{70}$+ 30 t/ha manure.

Annual application of rates of N_{160}+100 P_2O_5, in a four-year crop rotation (soybean-wheat-sugar beet-maize) + a reserve field, cultivated with legumes and perennial grasses, has determined the accumulation of a reserve of mobile phosphates in soil of 78 mg kg^{-1} (*Figure 3*).

Because of the high potassium consumption from soil by soybean, wheat and maize crops, grown under irrigated, the content of mobile potassium from soil decreased until 164-176 mg/kg soil, when the rate of $N_{80}P_{70}$+ 30 t/ha manure was applied (*Figure 4*).

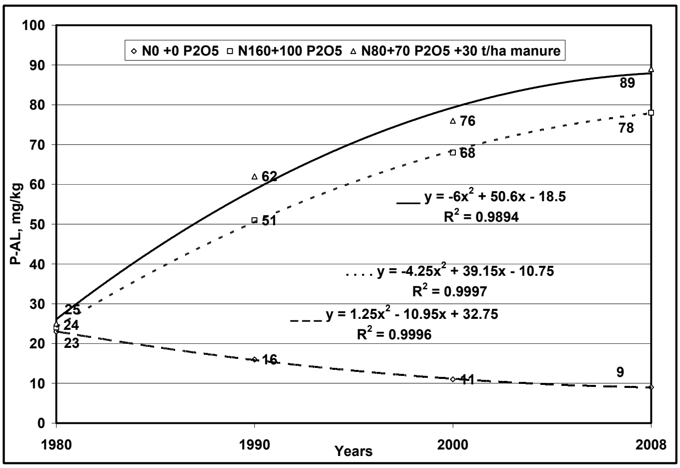

Fig. 3 - Change of mobile phosphate content from soil, cultivated for 28 years under irrigated, at different fertilizer rates

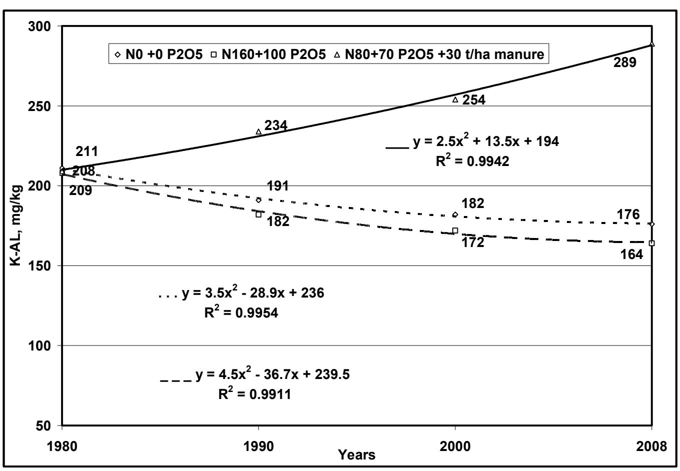

Fig. 4 - Change of mobile potassium content from soil, cultivated for 28 years under irrigated, at different fertilizer rates

CONCLUSIONS

The mean wheat yield, obtained at different fertilizer rates, during 1980-2008, under unirrigated, was of 3520 kg/ha, and it increased at 4569 and 4861 kg/ha, respectively (30-38%), by applying watering rates of 400 and 600 m^3/ha.

Under irrigated, the high nitrogen rate fertilization resulted in the diminution of organic carbon from soil, in comparison with organo-mineral fertilization, which shows an intensification of burning processes of the organic matter.

Long-term use of high nitrogen rates (N_{160}) has determined the pH decrease from 7.8 to 5.6, under irrigated.

Annual application of rates of N_{160} P_{80}, in a four-year crop rotation (soybean-wheat-sugar beet-maize) + a reserve field, cultivated with legumes and perennial grasses, determined the accumulation of mobile phosphate reserve of 78 mg/kg soil.

Under irrigated, a good plant supply with mineral elements and the increase in the content of organic carbon from soil were done by applying the rate of $N_{80}P_{70}$+ 30 t/ha manure.

Nitrogen and phosphorus fertilizers, although applied at high rates (N_{130} +100 P_2O_5), could not prevent the decrease in organic carbon content from soil.

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