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SOIL QUALITY AND CROP YIELDS, AFTER UTILIZATION OF SEWAGE SLUDGE ON AGRICULTURAL LAND, IN THE MOLDAVIAN PLAIN, ROMANIA

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ABSTRACT. Investigations conducted at the Podu-Iloaiei Agricultural Research Station, Iaşi County, have studied the influence of different sewage sludge rates on yield quality and quantity and soil agrochemical characteristics. Trials were set up in a five year-crop rotation, winter rape-wheat-maize-sunflower-wheat. Sewage sludge was applied every 2 years at rates of 20, 30, 40 and 60 t/ha, with different mineral fertilizer rates, differentiated according to the growing plant. The Cambic Chernozem used for experiments had a clayey-loam texture (410 g clay, 310 g loam and 280 g sand), a weakly acid reaction and a mean supply with mobile phosphorus and a very good one with mobile potassium. Applying rates of 30 t/ha sewage sludge has resulted in the accumulation of mobile phosphate stock in soil of 57 mg/kg and the microelement content, mobile forms from soil, was of 7.9 mg/kg at Cu, 1.4 mg/kg at B, 6.8 mg/kg at Zn and 186 mg/kg at manganese. The combined use of mean rates of mineral fertilizers ($N_{100}P_{80}$), together with 40 t/ha sewage sludge has resulted in improving soil chemical characteristics and getting yield increases in winter rape of 1854 kg/ha (108 %). After 8 years since the application of a rate of 30 t/ha sewage sludge, soil pH has increased 0.4 units, while phosphorus and potassium content from soil has increased by 30 and 52 mg/ kg soil, respectively. Sewage sludge from the Iaşi Water Treatment Station, which was applied every two years at rates of 20 and 30 t/ha, has determined the increase in the organic carbon content from soil by 2.9 g/kg (18%) and 4.4 g/kg (28%), respectively, compared to the unfertilized variant. The copper and zinc content from grains in wheat and maize crops, fertilized with 30 t/ha sewage sludge, was by two-four times higher, compared to the unfertilized control.

Key words: sewage sludge, organic carbon, heavy metals, winter rape, wheat, maize

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REZUMAT - Calitatea solului şi a recoltelor, după utilizarea nămolurilor de epurare pe terenurile agricole, în Câmpia Moldovei. Cercetările efectuate la Staţiunea de Cercetare Dezvoltare Agricolă Podu-Iloaiei, jud. Iaşi, au urmărit influenţa diferitelor doze de nămoluri asupra cantităţii şi calităţii producţiei şi asupra însuşirilor agrochimice ale solului. Experienţele au fost organizate într-un asolament de 5 ani - rapiţă de toamnă-grâu-porumb- floarea soarelui-grâu. Nămolurile s-au aplicat o dată la 2 ani, în doze de 20, 30, 40 şi 60 t/ha, împreună cu diferite doze de îngrăşăminte minerale, diferenţiate în funcţie de planta de cultură. Cernoziomul cambic folosit pentru experienţe are o textură luto-argiloasă (410 g argilă, 310 g lut şi 280 g nisip), o reacţie slab acidă , un nivel mediu de aprovizionare cu fosfor mobil şi unul foarte bun cu potasiu mobil. Aplicarea unor doze de 30 t/ha nămol orăşănesc a determinat acumularea unei rezerve de fosfaţi mobili în sol de 57 ppm, iar conţinutul de microelemente, forme mobile în sol, a fost de 7.9 mg/kg Cu, 1.4 mg/kg B, 6.8 mg/kg Zn şi 186 mg/kg mangan. Folosirea combinată a dozelor medii de îngrăşăminte minerale ($N_{100}P_{80}$), împreună cu 40 t/ha namol fermentat, a îmbunătăţit caracteristicile chimice ale solului şi a determinat, în comparaţie cu varianta martor nefertilizată, creşterea producţiei la rapita de toamna cu 1854 kg/ha (108 %). După 8 ani, prin aplicarea dozei de 30 t/ha nămol fermentat, pH-ul solului a crescut cu 0.4 unităţi şi conţinutul de fosfor şi potasiu din sol a crescut, faţă de varianta martor netratată, cu 30 şi, respectiv, 52 mg/kg sol. Nămolurile fermentate de la Staţia de epurare Iaşi, aplicate o dată la 2 ani, în doze de 20 si 30 t/ha, au determinat creşterea conţinutului de carbon organic din sol, în comparaţie cu varianta netratată, cu 2.9 (18%) şi, respectiv, 4.6 g/kg (28%). Conţinutul de cupru şi zinc din boabe la culturile de grâu şi porumb, fertilizate cu 30 t/ha nămol, a fost de două-patru ori mai mare, comparativ cu varianta martor nefertilizată.

Cuvinte cheie: nămoluri fermentate; carbon organic; metale grele; rapiţă de toamnă, grâu, porumb.

INTRODUCTION

In the last period, the investigations conducted in different countries have followed the influence of improving technological elements on fertilization and crop rotations with legumes and perennial grasses, which determine the increase in the content of organic carbon from soil. Investigations conducted during 2004-2011 at the Podu-Iloaiei Agricultural Research Station, Iaşi County, have studied the influence of different sewage sludge and fertilizer rates on yield quality and quantity and soil agrochemical characteristics. In soils from the Moldavian Plateau poor in organic matter and nutrients, the proper use of different crop rotation and organic resources may replace a part of rich technological consumption, determine the improvement in the content of organic matter from soil and ensure better conditions for the capitalization of nitrogen fertilizers.

The successive application for seven years of a rate of 100 t/ha municipal sewage sludge in wheat and maize crops, placed on a soil with silt clay loam texture determined the decrease of soil bulk density from 1.37 to 1.03 t/m^3, compared to unfertilized control, and the increase with a percent of organic carbon from soil (Aghilinategh *et al.*, 2009). Composting of municipal sewage sludge used in agriculture depends on the production of good quality compost, which is mature and low in metals and salt content. The best method of reducing metal content and improving the quality of municipal sewage sludge is early source of separation (McGrath *et al.,* 1994; Ailincăi *et al.,* 2007; Hargreaves *et al.,* 2008). All the countries are concerned by finding other nutrient sources, using legumes, manure, straw and composted sewage sludge (Alberici *et al.,* 1989, Andersson et *al.,* 1976; Dowdy *et al.,* 1994; Epstein and Chaney, 1978; Wright *et al.,* 2007). Other nutrient sources supplement only a small part of the necessary of nutrients available for the world food demand. This will increase with 1%/year or with 6.3 billion nowadays to 8.3 billion in 2030 and 10 billion in 2070. The sewage sludge, rich in organic matter and mineral elements for plants, can be a substitute for the fertilization but also a source of heavy metals pollution for soil, when high rates are applied or when it is used for many years on the same field. The use of sewage sludge in agriculture is one of the most important alternatives. Applying sewage sludge determines the modification of soil physical, chemical and biological characteristics and getting higher yields, as compared to the unfertilized control (Singh and Agrawal, 2008).

The sewage sludge application on acid soils from Larissa, Greece has resulted in increasing pH and the content of organic matter, nitrogen and phosphorus from soil (Tsadilas *et al.,* 2005). Metal sorption depends on the nature of organic and inorganic soil constituents, as well as soil pH (Antoniadis *et al.,* 2007).

MATERIALS AND METHODS

The aim of the study was to investigate the influence of sewage sludge application on winter rape and maize yield and quality and soil chemical characteristics. Experiments were set up in a five year-crop rotation (winter rape-wheat-maize-sunflower-wheat). Sewage sludge was applied at rates of 20, 30, 40 and 60 t/ha, with different mineral fertilizer rates, differentiated according to the growing plant. In wheat, we have used Gabriela Variety, in maize, Oana Hybrid and in winter rape, Bravour Variety. The soil used for the experiments was a cambic chernozem with a clayey-loam texture (410 g clay, 310 g loam and 280 g sand), a weakly acid reaction in the upper layer, average humus content and an average nutrient supply. Experiments were conducted in randomized blocks with split plots in six replicates. Composite surface soil samples consisted of five sub samples taken from 0 to 20 cm layer at each experimental plot in the spring before fertilization and in the autumn just after maize harvest. Soil samples were air dried, ground, and sieved with a 2 mm sieve prior to analysis. 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 (Nelson and Sommers, 1982). Soil pH was determined in water suspension 1:1 soil to water (McLean, 1982) and available phosphorus, using the $NaHCO_3$ method (Olsen and Sommers, 1982); and exchangeable potassium, using the NH_4OAc method (Thomas, 1982).

Soil reaction, depth of ground water (5-10 m) and concentrations of salts (6-85 mg in 100 g soil) did not limit the sewage sludge application. For soil treated with sewage sludge, the analyses for pH determination and contents of N, P, Cd, Cr, Cu, Hg, Ni, Pb and Zn were done at a depth of 20 cm. The concentrations of polluting heavy metals obtained from crop yield were measured according to standard methods, using atomic adsorption spectrometry. ANOVA was used to compare treatment effects.

RESULTS AND DISCUSSION

The climatic conditions in the Moldavian Plain were characterized by a mean multiannual 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.

Figure 1 – Sewage sludge from Iaşi Waste Water Treatment Station, applied to winter oilseed rape, Bravour Variety

At the Iaşi Municipal Sewage Water Treatment Station, one of the largest in Romania, producing about 3600 t/day of processed sludge. The fermented sludge from the Iaşi Municipal Treatment Station had a neutral reaction and an organic carbon content of 30-34% (*Figure 1*). The concentration of nitric nitrogen was low (0.175-0.469 ppm) and that of ammoniacal nitrogen between 30 and 820 mg/kg. Composting of municipal sewage sludge used in agriculture depends on the production of good quality compost, which is mature and low in metals and salt content. The total macronutrient contents (N, P, K, Ca, Mg) from fermented sludge were 1.56% total N, 1.20% total P, 4.40% total K, the calcium content was higher (3.12%), and organic S and Mg had normal values comparable to those from untreated soils. The total content of heavy metals of fermented sludge was low, comparable to that of untreated soils, and was below the maximum permitted value for sludge's, in order for them to be used as fertilizers for soils. The sewage sludge from the Iaşi Station contained more zinc and copper (*Table 1*). These elements could be used in maize and beans crops, where zinc deficit was frequent. Out of the nine studied heavy metals (Co, Cd, Cr, Cu, Fe, Mn, Ni, Pb and Zn), only zinc concentration had high values. The concentration of other heavy metals from fermented sewage sludge was similar to the normal content from soils. The analysis of sewage sludge from Iaşi Water Treatment Station applied to crops on a cambic chernozem at Podu-Iloaiei, Iaşi County, showed that in 2004 -2010, only zinc exceeded the limits established by EU regulations and Romanian law (Order No. 49/01.14.2004) (*Table 1*). Due to industrial treatment during the past years, heavy metals content have been reduced in sewage sludge. The concentration of other heavy metals from fermented sewage sludge was similar to the normal content from soils.

Heavy metal content from fermented sewage sludge at the Iaşi Municipal Treatment Station was higher at zinc (2318 mg/kg) and copper (53.7 mg/kg), requiring the limitation of sewage sludge rate to 20-30 t/ha.

Utilization of sewage sludge in agriculture has a major interest, due to nitrogen, phosphorus, potassium and microelement supply (Zn, Cu). Organic resources as sewage sludge, correctly applied, could be a substitute for a great part of expensive mineral nutrients and could contribute to the improvement of organic matter content from soil. The results have shown that the application of a rate of 30 t/ha sewage sludge determined the increase in plant supply degree with mineral elements, especially, N and P. It has also provided a mean annual supply of 8-12 t/ha organic matter, highly humificated, which explained the increase in soil organic carbon content from 16.5 g/kg to 21.1 g/kg (*Table 2*). Initially, soil pH was about 6.7, phosphorus 27 mg/kg and total N

0.141%. By using sewage sludge, plant nutrition was improved in secondary nutrients (calcium, manganese and sulfur) and in micronutrients (boron, copper, manganese and zinc). The micronutrients essential to plant growth are boron (B), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), nickel (Ni), and zinc (Zn).

Table 1 - Content of heavy metals in sewage sludge from the Iaşi Water Treatment Station, used for experiments (mg/kg dry matter)

Element	Year				Average	LSD 5%	*Romanian Order No. 49
	2004	2006	2008	2010			
Cd	3.6	3.3	2.7	1.7	2.8	0.09	10
Cr	87	73.8	76	38.6	68.9	4.3	500
Cu	42.9	61.3	68.7	41.9	53.7	3.5	500
Hg	1.9	1.8	1.5	0.9	1.5	0.06	16
Ni	38	63.5	52	35.1	47.2	3.4	100
Zn	2475	2461	2542	1793	2318	112	2000
Pb	186.8	163.6	152	113.6	154.0	11.3	300
Fe	20668	24559	32028	20563	24455	523	-
Mn	314.7	325	432	337	352	17.3	-
Co	36.5	32.7	26	7.9	25.8	2.1	50

*Maximum allowable concentrations (mg/kg DM) sewage sludge used in farming, according to Romanian Order No. 49

Table 2 - The evolution of chemical characteristics under the influence of sewage sludge applied on the cambic chernozem at the Podu-Iloaiei Agricultural Research Station

Agrochemical indices	Unfertilized control	Applied rates			LSD 5%
		20 t/ha sewage sludge, DM	30 t/ha sewage sludge, DM	N100P80 + 30 t/ha sewage sludge, DM	
pH, H_2O	6.7	6.9	7.1	6.9	0.10
Nt, %	0.141	0.191	0.194	0.197	0.02
P-AL, ppm	27	52	57	67	4.2
K-AL, ppm	233	266	285	292	13.0
Soil organic C (g/kg)	16.5	19.4	21.1	21.9	0.31

Much research has established the importance of fertilizers in increasing the fertility of soil and in influencing its productivity. Sommers obtained data on the nutrient content in 250 sewage sludge samples from 150 wastewater treatment plants. For anaerobically digested biosolids, organic N ranged from 0.501 to 3.033% and ammonium nitrogen

(NH_4^+-N) ranged from 0.0026 to 0.3760%. Numerous studies attempted to evaluate the losses of N from land application of biosolids (McGrath *et al.,* 1994; Adamsen and Sabey, 1987; Ailincăi *et al.,* 2007; Blair *et al.,* 2006). The characteristics of sewage sludge play an important part in their use for land application. Chemical properties affect plant growth as well as the soil's chemical and physical properties. The important chemical characteristics are pH and macro and micro plant nutrients. Sewage sludge can be an important source of plant macro and micronutrients for agricultural crops. Limits to annual additions of metals to soil based on a 10-year average is 6 g/ha Cd and 4500 g/ha Zn. The application of rates of 30 t/ha sewage sludge has resulted in the accumulation of mobile phosphates in soil of 57 mg/kg. The application of rates of 30 t/ha sewage sludge has resulted in the accumulation of microelements, mobile forms from soil, was of 8.0 mg/kg at Cu, 1.4 mg/kg at B, 6.8 mg/kg at Zn and 186 mg/kg at manganese (*Figure 2).*

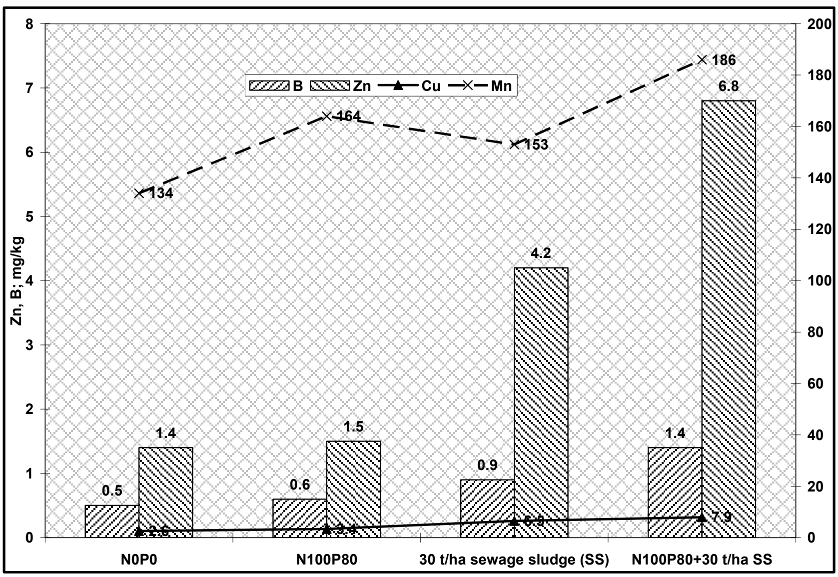

Figure 2 - Content of heavy metals from soil (mg/kg DM) at different rates of mineral fertilizers and sewage sludge, applied on the cambic chernozem of the Podu-Iloaiei Agricultural Research Station

The conditions regulating the application of sewage sludge on certain soils are set out in Norm 86/278/EEC, supplemented by EC Norm 466/2001 and by internal legislation. The current and projected heavy metal limit values, proposed by the European Union (EU) are in

Table 3. Member States are required to introduce legislation on waste collection, recycling and disposal of this waste. In 2006 the new Waste Framework Directive 2006/12/EC and the Waste Shipment Regulation (EC) No 1013/2006 were adopted by the European Parliament with the aim to strengthen the control procedures applicable to waste management.

Table 3 - Limit values for concentrations of heavy metals in sewage sludge and limits to annual additions of metals to soil based on a 10-Year average

Heavy Metal	Current		Proposed 2015		Proposed 2025	
	Limit Values for Concentrations mg/kg dm	Limit Values for Annual Additions g/ha/y	Limit Values for Concentrations mg/kg dm	Limit Values for Annual Additions g/ha/y	Limit Values for Concentrations mg/kg dm	Limit Values for Annual Additions g/ha/y
Cd	20-40	150	5	15	2	6
Cr	-	-	800	2400	600	1800
Cu	1000-1750	12000	800	2400	600	1800
Hg	16-25	100	5	15	2	6
Ni	300-400	3000	200	600	100	300
Zn	2500-4000	30000	2000	6000	1500	4500
Pb	750-1200	1500	1500	1500	200	600

Table 4 shows the maximum acceptable heavy metal concentrations and maximum acceptable heavy metal additions to soil as recommended by the Ministry of Agriculture from Canada and United States Environmental Protection Agency (USEPA). Rules on the use of sewage sludge in farming require various sewage sludge treatments and limits on the allowed content of polluting substances. Biosolids are the only beneficial waste that is regulated by the United States Environmental Protection Agency (USEPA). These regulations pertain to land application of biosolids, including compost and other forms of transformed sewage sludge materials. Ceiling concentration is the maximum concentration in mg/kg of heavy metal in sewage sludge that is allowed for land application. If sewage sludge contains pollutants above these levels, the products may not be applied to land. Annual pollutant loading rate (APLR) is the highest annual rate of application of each pollutant to land in kg/ha and cumulative pollutant loading rate (CPLR) is the maximum amount of pollutant that can be applied to an area of land (*Table 4*). Below this limit, other criteria may restrict its use. States may issue regulations that have lower limits, but not higher ones.

Table 4 - Maximum acceptable heavy metal concentrations in sewage sludge and maximum acceptable cumulative heavy metal additions to soil

Element	The USEPA regulations			AgriFood Canada	
	Ceiling Concentration Limits for all Biosolids Applied to Land, mg/kg Dry-weight	Cumulative Pollutant Loading Rate Limits for CPLR Biosolids, kg/ha	Annual Pollutant Loading Rate Limits for APLR Biosolids, kg/ha/365-Day Period	Maximum Acceptable Metal Concentrations, mg/kg	Maximum Acceptable Cumulative Heavy Metal Additions to Soil, kg/ha
Arsenic	75	41	2.0	75	15
Cadmium	85	39	1.9	20	4
Copper	4300	1500	75	150	30
Lead	840	300	15	500	100
Mercury	57	17	0.85	5	1
Molybdenum	75	-	-	20	4
Nickel	420	420	21	180	36
Selenium	100	100	5.0	14	2.8
Zinc	7500	2800	140	1850	370

Romania has elaborated normative acts where there are established maximum allowable values for the content of heavy metals in sewage sludge and soils according to Annex 1 of Norm 86/278/ EEC. These normative acts allow the utilization in farming of residual sewage sludge from wastewater treatment stations. The Government Decision forbids the use of sewage sludge when the concentration of one or more heavy metals in the soil exceeds the established allowable limits. For the assessment of fields and crops suitable for treatment with sewage sludge, the stipulations of Order No. 49 (01.14.2004) need to be observed.

The climatic conditions recorded during 2004-2011 have resulted in a good valorization of mineral fertilizers and sewage sludge in main crops. The climatic conditions in the Moldavian Plain were characterized by a mean multiannual temperature of 9.6°C and a mean rainfall amount, on 50 years, of 553.4 mm, of which 141.4 mm, during September-December, and 412.0 mm, during January-August (*Table 5*). The climatic conditions during 2004-2011 were favourable to plant growing and development in three years, and unfavourable in the other five years, because of reduced rainfall. Average rainfall amounts, recorded during 2004-2011, from January to August, were higher with 52.2 mm, compared to the multiannual average on 50 years (412 mm) (*Table 5*). During 2004-2011, the climatic conditions were favorable to plant growing and development in 4 years in winter rape and 5 years in maize.

Table 5 - Rainfall recorded at the Weather Station of Podu-Iloaiei, during 2004 - 2011 (mm)

Years / month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	Total
2004	67.9	31.3	18.5	16.8	19.8	20.7	125.3	99.1	61.6	25.2	42.1	11.1	**539.4**
2005	42.4	42.1	25.6	86.2	106.0	86.3	64.7	160.0	14.3	21.7	47.0	30.1	**726.4**
2006	29.3	7.8	97.3	98.0	57.0	93.7	163.0	121.5	18.9	18.1	6.3	2.6	**713.5**
2007	20.3	30.2	30.2	27.0	30.7	15.6	63.6	63.6	108.7	91.4	46.8	54.0	**582.1**
2008	10.9	2.6	25.2	127.3	43.2	65.2	145.1	48.0	52.0	53.1	13.4	39.9	**625.9**
2009	80.0	56.5	37.5	5.0	44.0	139.0	122.0	12.1	25.0	87.0	9.0	35.0	**652.1**
2010	61.0	17.2	20.2	24.3	82.0	173.0	73.0	7.3	59.0	7.3	10.8	27.0	**562.1**
2011	19.6	15.6	16.4	68.0	37.0	81.0	80.1	12.0	13.0	34.0	2.0	6.0	**384.7**
Average	**41.4**	**25.4**	**33.9**	**56.6**	**52.5**	**84.3**	**104.6**	**65.5**	**44.1**	**42.2**	**22.2**	**25.7**	**598.4**
Average on 50 years	**26.0**	**22.2**	**28.8**	**49.4**	**55.3**	**85.2**	**87.4**	**57.7**	**51.0**	**32.9**	**31.2**	**26.3**	**553.4**
Difference	**15.4**	**3.2**	**5.1**	**7.2**	**-2.8**	**-0.9**	**17.2**	**7.8**	**-6.9**	**9.3**	**-9.0**	**-0.6**	**45.0**

The climatic conditions recorded resulted in a good uptake and use of mineral fertilizers and manure by the main crops. The mean yield obtained in winter rape was of 1720 kg/ha in unfertilized control and 3574 kg/ha at the rate of 40 t/ha sewage sludge + $N_{100}P_{80}$ (*Table 6*). The mean yield increases obtained in the last four years in winter rape, by applying rates of 40 t/ha sewage sludge, were of 1499 kg/ha (87%), compared to untreated control. Mean yield increases obtained in winter rape, for each tone of sewage sludge, were of 16.88 kg/t. Nitrogen and phosphorus fertilizers resulted in mean yield increases of 1544 kg/ha (90 %) , while sewage sludge applied at rates of 40 and 60 t/ha resulted in yield increases of 1499 (87 %) and, respectively, 1678 kg/ha (98 %).

Table 6 - Influence of sewage sludge and mineral element fertilization on winter rape yield (Bravour Variety)

Treatment	Mean yield		Difference, kg/ha	Signiff.
	kg/ha	%		
Unfertilized control	1720	100		
$N_{100}P_{80}$	3264	190	1544	xxx
20 t/ha sewage sludge	2716	158	996	xxx
20 t/ha sewage sludge+ $N_{100}P_{80}$	3452	201	1732	xxx
40 t/ha sewage sludge	3219	187	1499	xxx
40 t/ha sewage sludge+ $N_{100}P_{80}$	3574	208	1854	xxx
60 t/ha sewage sludge	3398	198	1678	xxx
60 t/ha sewage sludge+ $N_{100}P_{80}$	3628	211	1908	xxx
Yield (Y) = 2256.9 + 3.98 NP (kg/ha) + 16.88 sewage sludge (t/ha), R^2=0.772, obs=8				
LSD 5%= 256 kg/ha, LSD 1%= 350 kg/ha, LSD 0.1% = 468 kg/ha				

The uptake of trace elements by plants is a function of the soil characteristics, climate, of the concentration of the element and plant species. Many soil and plant factors affect the bioavailability of trace elements and heavy metals to plants. The soil factors that affect trace element uptake are soil pH, organic matter, element interactions, soil water, soil temperature and soil aeration (Epstein, 1971; Epstein *et al.*, 1978). Organic matter has a high Cation Exchange Capacity (CEC) and contributes to the total CEC of soils and the binding power to heavy metals except those that occur as anions in the soil solution. Many researchers have found that the uptake of trace elements and regulated heavy metals by various crops was not linear with trace elements or sludge application rate. The availability of heavy metals to plants and their mobility through the soil is dependent on interactions with other elements. Accumulation in plants varies with the species, cultivars and organs within the plant. In general, heavy metals are concentrated in the leaves and stalks than in the grain (*Table 7*).

Table 7 - Contents of heavy metals in maize and wheat grains fertilized with sewage sludge (SS) from the Iaşi Water Treatment Station (mg/kg DM)

Element	Wheat				Maize			
	Grain		Straw		Grain		Stalks	
	Control	SS-30 t/ha	Control	SS-30 t/ha	Control	SS-30 t/ha	Control	SS-30 t/ha
Zn mg/kg	13.9	15.8	15.8	18.9	15.2	24.6	16.3	24.3
Cu mg/kg	0.13	0.54	3.7	7.1	0.21	0.26	3.8	5.2
Ni mg/kg	-	-	0.07	0.1	0.04	0.08	0.4	0.7
Cd mg/kg	-	-	-	-	<0.01	0.01	0.02	0.04
Co mg/kg	-	-	-	-	-	-	-	<0.01
Pb mg/kg	-	-	-	-	-	-	0.04	0.07
Fe mg/kg	7.18	9.12	9.81	21.7	6.89	7.62	12.32	28.6
Mn mg/kg	0.26	0.59	0.51	0.53	0.12	0.16	0.47	0.49
Nt %	1.42	2.04	0.35	0.61	1.14	1.29	0.33	0.48
K%	0.38	0.49	0.54	0.91	1.21	1.38	0.43	0.62
P%	0.47	0.51	0.143	0.146	0.463	0.50	0.131	0.141

The concentration of Zn in plant species varies widely. Zn deficiency in plants as a result of low Zn in soil occurs in many of the areas of the Moldavian Plateau. Zn deficiency in plants occurred when Zn levels were less than 15 to 20 mg/kg dry matter and is associated with high-pH soils or with coarse-textured, highly leached acid soils. The heavy metal contents of the farm produces were within the normal limits for Cu and Ni, while Cr, Co, Cd, Pb and Hg were not present in plants and grains, or only as traces in a few plants (*Table 7*).

The maize grain contained significantly lower concentrations of the metals than the stalks. Cadmium and Zn concentrations in maize stalks and grain increase with sludge applications. These results also showed that the only criterion limiting the rate of fermented sewage sludge at 20-30 t/ha dry matter was zinc content. These rates should be increased on soils, which are deficient in zinc. Zinc and copper content in the plants treated with high rates of sewage sludge were higher in maize cobs. This fact should be also taken into account when the rates of sewage sludge are established for this crop, especially on low pH soils. The copper and zinc content from grains in wheat and maize crops, fertilized with 30 t/ha sewage sludge, was by two-four times higher, compared to the unfertilized control. These results showed that sewage sludge, applied in maize crops did not affect the quality of yield.

CONCLUSIONS

In soils from the Moldavian Plain, most of them poor in organic matter and nutrients, the proper use of different organic resources may replace a part of expensive technological consumption, determines the improvement in the content of organic matter from soil and ensures better conditions for the capitalization of nitrogen fertilizers.

Analysis of contents of heavy metals in soil, sewage sludge and farm produce has shown that sewage sludge from Iasi station is within the present requirements of Romanian legislation and the EU (Norm 86/278/EEC). The fermented sewage sludge from Iasi station, by its chemical and biological characteristics, can be used as fertilizer on most soils, except for saline soils, due to its high content of soluble salts (1.1 g/100 g dry sewage sludge), and amendment measures would be necessary in these cases.

After 8 years since the application of a rate of 30 t/ha sewage sludge, soil pH has increased 0.4 units, while phosphorus and potassium content from soil has increased by 30 and 52 mg/kg soil, respectively.

Sewage sludge from the Iaşi Water Treatment Station, which was applied every two years at rates of 20 and 30 t/ha, has determined the increase in the organic carbon content from soil by 2.9 g/kg (18%) and 4.6 g/kg (28%), respectively, compared to the unfertilized variant.

Utilization of sewage sludge in agriculture has a major interest, due to nitrogen and phosphorus and microelements supply, Zn, Cu, B, and Mn.

Applying rates of 30 t/ha sewage sludge has resulted in the accumulation of mobile phosphate stock in soil of 57 mg/kg and the microelement content, mobile forms from soil, was of 7.9 mg/kg at Cu, 1.4 mg/kg at B, 6.8 mg/kg at Zn and 186 mg/kg at manganese.

The combined use of mean rates of mineral fertilizers ($N_{100}P_{80}$), together with 40 t/ha sewage sludge has resulted in improving soil chemical characteristics and getting yield increases in winter rape of 1854 kg/ha (108 %).

Maximum sewage sludge rate, which may be applied on fields, without exceeding the maximum charge rates of 30 kg/ha/year for zinc and 12 kg/ha/year for copper, foreseen by Directive 86/278/EEC and Order of Romanian Government no. 49 from 14 January 2004, is of 30 t/ha.

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REFERENCES

Adamsen F.J. Sabey B.R., 1987 - Ammonia volatilization from liquid digested sewage sludge as affected by placement in soil, Soil Sci. Soc. Am. J. 51: 1080–1082.

Aghilinategh N., Hemmat A., Rezainejad Y., Sadeghi M., 2009 - Effect of Long-Term Incorporation of Organic Manure on Physical and Mechanical Properties of a Silty Clay Loam Soil, XXXIII CIOSTA - CIGR V Conference, Reggio Calabria, Italy, Technology and management to ensure sustainable agriculture, agrosystems, forestry and safety, Edit. Artemis, Volume 2, 1059-1063.

Ailincăi C., Jităreanu G., Bucur D., Ailincai Despina, 2007 – Influence of sewage sludge on maize yield and quality and soil chemical characteristics, Journal of Food, Agriculture & Environment, Vol. 5 (1), 310-313.

Alberici T.M., W.E. Sopper, G.L. Storm and R.H. Yahner, 1989 - Trace metal in soil, vegetation, and voles from mineland treated with sewage sludge, J. Environ. Qual. 18:115–120.

Andersson A. Nilsson K.O., 1976 - Influence on the levels of heavy metals in soil and plant from sewage sludge used as a fertilizer, Swedish J. Res. 6: 151–159.

Antoniadis V., Tsadilas Ch.D, Ashworth D. J., 2007 - Monometallic and competitive adsorption of heavy metals by sewage sludge amended soil, Chemosphfere 68, 489-494.

Blair Nelly, Faulkner R.D., Till A.R., Poulton P.R., 2006 - Long-term management impacts on soil C, N and physical fertility, Soil & Tillage Research 91, 30-38.

Dowdy R.H., Clapp S.E., Linden D.R., Larson W.E., Halbach T.R., Polta R.C., 1994 - Twenty years of trace metal partitioning on the Rosemont sewage sludge watershed, 149–155, C.E. Clapp, W.E. Larson and R.H. Dowdy (Eds.), Sewage Sludge: Land Utilization and the Environment, American Society of Agronomy, Madison, WI.

Epstein E., Chaney R.L., 1978 - Land disposal of toxic substances and water–related problems, J. Water Pollut. Control Fed. 50(8): 2037–2042.

Epstein E., 1971 - Effect of soil temperature on mineral element composition and morphology of the potato plant, Agronomy J. 63: 664–666.

Hargreaves J.C., Adl M.S., Warman P.R., 2008 - A review of the use of composted municipal solid waste in agriculture, Agriculture, Ecosystems & Environment, Volume 123, January 2008,1-14.

McGrath S.P., Chang M.C., Page A.L., Witter E., 1994 - Land application of sewage sludge: Scientific perspectives of heavy metal loading limits in Europe and the United States, Environ. Rev. 2:108–118.

McLean E.O., 1982 - Soil pH and lime requirements, In Methods of Soil Analysis Part 2: Chemical and Microbiological Properties, Page A. L. Miler R H and Keeney D R. (eds), SSSA Mdison, Wisconsin, 199-224.

Nelson D.W., Sommers, L.E., 1982 - Total carbon, organic carbon, and organic matter. In Methods of Soil Analysis, part 2: Chemical and Microbiological properties; Page, A.L., Miller, R.H. and Keeney, D.R. (eds); SSSA: Madison, Wisconsin, 539-579.

Olsen S.R., Sommers, L.E., 1982 - Phosphorus. In Methods of Soil Analysis, part 2: Chemical and Microbiological properties; Page, A.L., Miller, R.H. and Keeney, D.R. (eds); SSSA: Madison, Wisconsin, 403-430.

Singh R.P., Agrawal M., 2008 - Potential benefits and risks of land application of sewage sludge*,* Waste Management , 2008 28:2, 347-358.

Sommers L.E., 1977 - Chemical composition of sewage sludges and analysis of their potential use as fertilizers, J. Environ. Qua*l* . 6 (2): 225–232.

Thomas G.W., 1982 - Exchangeable cations. In Methods of Soil Analysis, part 2: Chemical and Microbiological properties; Page, A.L., Miller, R.H. and Keeney, D.R. (eds); SSSA: Madison, Wisconsin, 159-165.

Tsadilas C.D., Matsi T., Barbayiannis N., Dimoyiannis D., 2005 - Influence of Sewage Sludge Application on Soil Properties and the Distribution and Availability of Heavy Metal Fraction, Soil Science Laboratory, Aristotelian University, Thessaloniki, Greece, 2603-2618.

Wright A.L., Dou F., Hons F.M., 2007- Soil organic C and N distribution for wheat cropping systems after 20 years of conservation tillage in central Texas, Agriculture, Ecosystems & Environment, Vol. 121, August 2007, 376-382.