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Impacts of Using Mineral Fertilization Combined with Sewage Sludge in the Amendment of Luvisol on Oat Crop
I. Influence on Yield and Mineral Nutrition

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Abstract: The present paper illustrates the results obtained on oat (Avena sativa L.*), Someșan variety, concerning growth, grains and straw yields and also of macroelements accumulation (N, P, K, Ca, Mg) when various doses of sewage sludge were applied associated or not with mineral fertilization. Sewage sludge application produced significant increase of plant height starting with equivalent dose of 100 kg N/ha, meanwhile the highest height was observed in the case of plants fertilized with doses equivalent with 300 and 400 kg N/ha. With the increase of sewage sludge dose it has been observed the straw yield increase, this being statistically assured starting with sewage sludge equivalent dose of 100 kg N/ha. Sewage sludge fertilization, accompanied or not by mineral fertilizers, evidenced that nitrogen contents in oat grains increases with applied sewage dose, being significant from an equivalent dose of 200 kg N/ha. Low sewage doses equivalent with 200-300 kg K/ha evidenced for potassium concentration in oat grains a significant decrease in comparison with untreated variant, meanwhile mineral fertilization generated a significant increase of potassium levels in oat grains. Calcium contents in oat grains present a significant increase after sewage sludge fertilization and at a dose equivalent with 600 kg N/ha, the calcium levels (0.24%) increased 3 times in comparison with untreated variant (0.08%). Sewage sludge fertilization, associated or not with mineral fertilizers, did not produced significant changes of magnesium levels in oat grains, found concentrations being considered as normal values.*

Keywords*: grains, mineral fertilization, oat, sewage sludge, yield.*

1. Introduction

Resulted from municipal wastewater treatment plants, sewage sludge is a nutrient rich organic material, used as fertilizer and soil conditioner. Considerable number of research papers has been accomplished worldwide on the effects of sewage sludge on soil and various crops. Hence, some studies indicated that successive application during seven years of 100 t/ha municipal sewage sludge for wheat and maize crops produced an increase with a percent of organic carbon from soil [1,2]. Other researches evidenced that sewage sludge application presented a positive influence on the content of total organic carbon and humus fractions [3]. Organic fertilization with compost obtained from municipal sludge with a dose of compost equivalent to 400 kg N/ha led to significant increases of mobile phosphorus levels in soil [4].

Mihalache et al [5] reported that sewage sludge application generate significant increase of soil organic carbon, total nitrogen, mobile forms of phosphorus and potassium, the highest effects being encountered for 240 t/ha sewage sludge dose.

There are many scientific reports that highlight the enhancement of crop productivity and crop quality parameters after sewage sludge application. Accordingly, application of 0, 40, 80, 120, 240 t/ha sewage sludge at rice crop evidenced that rate of 240 t/ha produced highest number of filled grains per panicle, dry weight of grains and weight of 1000 grains [6]. The efficiency of sewage sludge

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application on maize [7,8], sunflower [9,10], wheat [11], growth, yield, macroelements and metals accumulation was evidenced and reported. Also, positive effects on yield of dwarf bean [12] and growth of flax [13] have been reported at application of different doses of sewage sludge.

Fertilization with compost from municipal sludge associated with mineral fertilization led to better yields for various crops (oat, maize, soybean) in comparison with one type of fertilization [4]. Better crop parameters could be also achieved by using some promising materials, such as essential oils microcapsules [14].

Because of the presence of toxic heavy metals [15], organic pollutants [16-18] and pathogenic organisms [18,19], sewage sludge may present environmental risk. To eliminate the presence of pathogens in sewage sludge it is recommended to adopt some techniques as digestion and/or radiation [20]. A positive effect of sewage sludge (irradiated or not) was reported regarding dry matter yield and nitrogen uptake for wheat crop [20].

Having in view the acknowledged beneficial influence of sewage sludge application to different crops, the purpose of the present research was to investigate the sewage sludge effects on growth, yield responses and macronutrients (N, P, K, Ca, Mg) accumulation for oat (*Avena sativa* L.).

The developed experimental model was a bifactorial one (7x2) and the studied factors were: **A factor** – sewage sludge fertilization with 7 degrees representing equivalent doses varying between 0-600 kg/ha and **B factor** – mineral fertilization (NPK) with 2 degrees: b_1 – $N_0P_0K_0$ and b_2 – $N_{100}P_{100}K_{100}$.

2. Materials and methods

2.1. Experimental design

In order to study the influence of sewage sludge application on yield and mineral nutrition, was used oat (*Avena sativa* L.), Someșan variety, as test plant cultivated in experimental pots. For experimental model which is a bifactorial one (7x2) (table 1), it were used 56 vegetation pots (20 L capacity), each treatment (totalizing 14) in four repetitions. For experiments was used soil collected from A_0 horizon of luvisol meanwhile sewage sludge that was used in experiment was collected from the Wastewater Treatment Plant (WWTP) from Pitești.

Table 1. Description of bifactorial experimental model

a factor = equivalent doses of N provided by sewage sludge application		**b factor = type of applied fertilizer**	
a_1	0 kg N/ha	**b_1**	sewage sludge - without mineral fertilization, $N_0P_0K_0$
a_2	100 kg N/ha	**b_2**	sewage sludge and mineral fertilizer $N_{100}P_{100}K_{100}$ (fertilization 100 kg N/ha + 100 kg P/ha + 100 kg K/ha)
a_3	200 kg N/ha		
a_4	300 kg N/ha		
a_5	400 kg N/ha		
a_6	500 kg N/ha		
a_7	600 kg N/ha		

2.2. Chemical characterization of soil and sewage sludge

Soil and sewage sludge were fully characterized and the performed analyses are presented in Table 2.

Table 2. Chemical analyses performed on soil and sewage sludge

Parameter	**Soil**	**Sewage sludge**	**Method and *apparatus***
pH	✓	✓	potentiometric method (aqueous suspension, 1:2.5, w/v); ***pH-meter Hanna intruments***.
Organic matter ($C_{organic}$)	✓	✓	Walkley-Black-Gogoasa method for $C_{organic}$. Organic matter = $C_{organic}$ x 1.724.
Mobile phosphorus (P_{AL})	✓	-	Egner-Riehm-Domingo method; spectrophotometrically, as molybdenum blue; ***Cecil 2041 UV/VIS spectrophotometer***.

Mobile potassium (K_{AL})	✓	-	Egner-Riehm-Domingo method; atomic emission spectrometry (AES); ***Sherwood Scientific 420 flame photometer***.
Total nitrogen (N_{total})	✓	✓	Kjeldahl method; ***Gerhardt Vapodest automatic analyzer***.
Total phosphorus (P_{total})	-	✓	spectrophotometrically, as molybdenum blue; ***Cecil 2041 UV/VIS spectrophotometer***.
Total potassium (K_{total})	-	✓	atomic emission spectrometry (AES); ***Sherwood Scientific 420 flame photometer***.
Metals total forms	✓	✓	atomic absorption spectrometry (AAS), after *aqua regia* digestion [21,22]; ***Thermo Scientific AA Spectrometer***.

2.3. Plant sampling and chemical analysis

Plant samples were processed and then analyzed according to methodology described in a previous paper [7], based on Singh and Agrawal researches [23]. Total nitrogen content was evaluated using Kjeldahl method (*Gerhardt Vapodest automatic analyzer*), meanwhile total phosphorus was assessed spectrophotometrically as molybdenum blue (*Cecil 2041 UV/VIS spectrophotometer*) and potassium using AES technique (*Sherwood Scientific 420 flame photometer*). Contents of calcium and magnesium were determined after filtering the digested samples through AAS technique (*Thermo Scientific AA Spectrometer*).

3. Results and discussions

3.1. Soil and sewage sludge chemical characterization

The soil used in this experiment was taken from Ao horizon of Luvisol [24]. It had a loam texture, presented moderately acidic reaction (pH 5.20), low carbon organic content (1.19%) and low levels of macronutrients: N_{total} - 0.140%, P_{AL} - 19 mg/kg and K_{AL} - 40 mg/kg. The concentrations for metals (total forms) are: Cd - 0.11 mg/kg, Co - 6.60 mg/kg, Cr - 19 mg/kg, Cu - 12 mg/kg, Mn - 500 mg/kg, Ni - 15 mg/kg, Pb - 13 mg/kg and Zn - 48 mg/kg.

Sewage sludge chemical characteristics are depicted in table 3. It was analyzed 9 samples and according to the results, investigated sewage sludge contains high levels of organic matter (48.3%, as average) and presents a balanced macronutrient composition which recommends it as fertilizer.

Concerning metal composition of sewage sludge, it must be respected European Directive 86/278/CEE [25] and Order of the Minister of Agriculture, Forests, Waters and Environment no.344/2004 [26], metal content being a restrictive factor for sewage sludge application.

Excepting cadmium concentration which is 7.2 times higher than limit imposed by Order of the Minister of Agriculture, Forests, Waters and Environment no.344/2004 [26], found metal contents (as total form) in analyzed sewage sludge indicate that there are no restrictions concerning application it on agricultural soils and meet the requirements imposed by legislation [25,26].

Table 3. Sewage sludge chemical characterization

Sewage parameters	Determined values (min-max)	Average value ± standard deviation	Coefficient of variation, %	Restricted value	
				Order 344/2004 Romania [26]	Directive 86/278/EEC [25]
Water content, %	74.2-84.6	**77.8** ± 3.3	4.2	-	-
pH	6.83-6.90	**6.87** ± 0.02	0.3	-	-
Organic matter, %	47.2-50.0	**48.3** ± 0.9	1.9	-	-
N_{total}, %	1.82-2.53	**2.11** ± 0.22	10.4	-	-
P_{total}, %	0.66-0.79	**0.72** ± 0.05	6.9	-	-
K_{total}, %	0.33-0.48	**0.40** ± 0.05	12.5	-	-
Cd, mg/kg	54-84	**72** ± 9	12.5	**10**	**20-40**
Co, mg/kg	5.5-8.2	**6.6** ± 0.8	12.1	**50**	-
Cr, mg/kg	122-145	**135** ± 8	5.9	**500**	-
Cu, mg/kg	137-166	**154** ± 11	7.1	**500**	**1000-1750**
Mn, mg/kg	373-436	**400** ± 19	4.8	-	-
Ni, mg/kg	37-42	**40** ± 2	5.0	**100**	**300-400**

Pb, mg/kg	88-135	**106** ± 15	14.2	**300**	**750-1200**
Zn, mg/kg	1290-1932	**1492** ± 184	12.3	**2000**	**2500-4000**

3.2. Influence of sewage sludge application on height, grains yield and straw yield

The data regarding the influence of sewage sludge application associated or not with mineral fertilizers on height of oat plants Someșan variety, evidenced that sewage sludge application produce significant increase of plant height starting with equivalent dose of 100 kg N/ha (Table 4). The highest height was observed in the case of plants fertilized with doses equivalent with 300 and 400 kg N/ha.

The mixed application of sewage sludge and mineral fertilizers resulted in no statistically assured increases of oat plant height, these being similar with those obtained after sewage sludge fertilization solely.

With respect to grains yield, the application of sewage sludge produced very significant increase of grains yield; the lowest value, as average (30g/pot) was encountered for sewage sludge without mineral fertilization variants, meanwhile the highest one, as average (95g/pot) was obtained for sewage dose equivalent with 500 kg N/ha and 600 kg N/ha (Table 4). Mineral fertilization led to significant oat grains yield in comparison with unfertilized variant.

With the increase of sewage sludge dose it has been observed the straw yield increase, the increase being statistically assured starting with sewage sludge equivalent dose of 100 kg N/ha. The lowest straw yield, as average (25g/pot) was obtained for sewage sludge unfertilized variants and the highest, as average (100g/pot) was obtained after application of sewage sludge dose equivalent with 600 kg N/ha (Table 4). Mineral fertilization increased significantly the straw yield.

Sewage sludge application associated with mineral fertilizers does not provide significant statistical increases of grains yield and straw yield but these parameters are slightly higher in comparison with the variants fertilized organic only.

Some researchers [27] evidenced that the highest oat yields were obtained when was applied a dose of sewage sludge equivalent with 400 kg N/ha. Also, sewage sludge treatments at oat crop at doses equivalent with 200 kg N/ha led to the same yields as those obtained after application of 100 kg N/ha as ammonium sulphate [27].

Mihalache et al. [5] evidenced that fertilization with sewage sludge favored yield increase, but the production decreased with the increasing the application rate of sewage sludge (at 120 t/ha for oat and 90 t/ha for sugar beet).

Table 4. Influence of sewage sludge application (without/with mineral fertilization) on height, grain yield and straw yield

Sewage sludge		**Height,** cm			**Grains Yield,** g			**Straw Yield,** g		
		b_1	b_2	Av. (b)	b_1	b_2	Av. (b)	b_1	b_2	Av. (b)
a_1	0 kg N/ha	59	86	73a*	13	47	30a*	13	36	25a*
a_2	100 kg N/ha	83	90	87b	55	74	65b	40	59	50b
a_3	200 kg N/ha	87	94	91c	73	90	82c	55	74	65c
a_4	300 kg N/ha	93	94	94c	84	93	89d	65	86	76d
a_5	400 kg N/ha	93	94	94c	89	99	94d	75	100	88e
a_6	500 kg N/ha	91	91	91c	89	100	95d	76	99	88e
a_7	600 kg N/ha	92	89	91c	90	99	95d	90	109	100f
Av. (a)		85a*	91b	-	70a*	86b	-	59a*	80b	-

b_1 - corresponds to $N_0P_0K_0$ (without mineral fertilization), b_2 - corresponds to $N_{100}P_{100}K_{100}$ (mineral fertilization) Av. – average
*Mean values accompanied by same letter (a or b) does not present significant differences (Tukey multiple comparison test - significance level 0.05)

3.3. Influence of sewage sludge application on N, P, K contents in grains

Sewage sludge fertilization, accompanied or not by mineral fertilizers, evidenced that nitrogen contents in oat grains increases with applied sewage dose, being significant from an equivalent dose of 200 kg N/ha (table 5). Mineral fertilization led to statistic significant increases of nitrogen level in oat grains. Association of sewage sludge with mineral fertilizers did not led to statistic significant changes

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of nitrogen content, the nitrogen levels being slightly higher than those obtained after sewage sludge application only.

The obtained data, regarding sewage sludge fertilization, associated or not with mineral fertilizers, evidenced that no significant changes were recorded for phosphorus levels in oat grains (Table 5).

Concerning potassium content in oat grains after sewage sludge application, associated or not with mineral fertilizers, it was observed that at low doses equivalent with 200-300 kg N/ha, potassium concentration in oat grains present a significant decrease in comparison with untreated variant (table 5). Mineral fertilization generated a significant increase of potassium levels in oat grains.

Association and application of organic and mineral fertilizers did not produce significant potassium concentration, the obtained concentrations being similar with those obtained after sewage sludge application only.

Average concentrations for phosphorus and potassium in oat grains are in agreement with values reported for oat grains [28] and cereal grains [29,30].

Table 5. Influence of sewage sludge application (without/with mineral fertilization) on N, P and K contents in grains

Sewage sludge		**N, %**			**P, %**			**K, %**		
		b_1	b_2	Av. (b)	b_1	b_2	Av. (b)	b_1	b_2	Av. (b)
a_1	0 kg N/ha	1.35	1.46	1.41a*	0.28	0.28	0.28a*	0.83	0.85	0.84a*
a_2	100 kg N/ha	1.52	1.65	1.59ab	0.28	0.29	0.29a	0.76	0.77	0.77ab
a_3	200 kg N/ha	1.73	1.82	1.78b	0.29	0.29	0.29a	0.67	0.70	0.69b
a_4	300 kg N/ha	1.84	1.94	1.89bc	0.32	0.32	0.32a	0.67	0.76	0.72b
a_5	400 kg N/ha	2.02	2.27	2.15cd	0.31	0.33	0.32a	0.80	0.85	0.83a
a_6	500 kg N/ha	2.10	2.40	2.25d	0.28	0.31	0.30a	0.76	0.88	0.82a
a_7	600 kg N/ha	2.27	2.57	2.42d	0.29	0.31	0.30a	0.76	0.93	0.85a
Av. (a)		1.83a*	2.02b	-	0.29a*	0.30a	-	0.75a*	0.82b	-

b_1 - corresponds to $N_0P_0K_0$ (without mineral fertilization), b_2 - corresponds to $N_{100}P_{100}K_{100}$ (mineral fertilization) Av. - average
*Mean values accompanied by same letter (a or b) does not present significant differences (Tukey multiple comparison test - significance level 0.05)

In the case of applied sludge with and without mineral fertilization, the corresponding nitrogen doses correlate statistically very strong with the nitrogen content in grains.

The phosphorus and potassium content in grains analysis correlated with the nitrogen doses resulting from variants with sludge and mineral fertilization reveals statistically strong correlation coefficients (Figures 1, 2, 3).

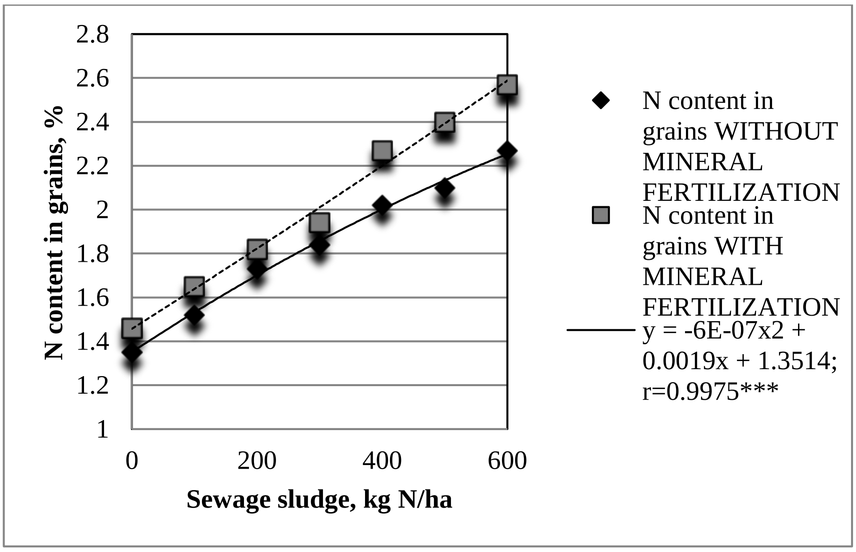

Figure 1. Correlation between nitrogen content in grains and applied nitrogen dose (*** very strong correlation, p<0.001)

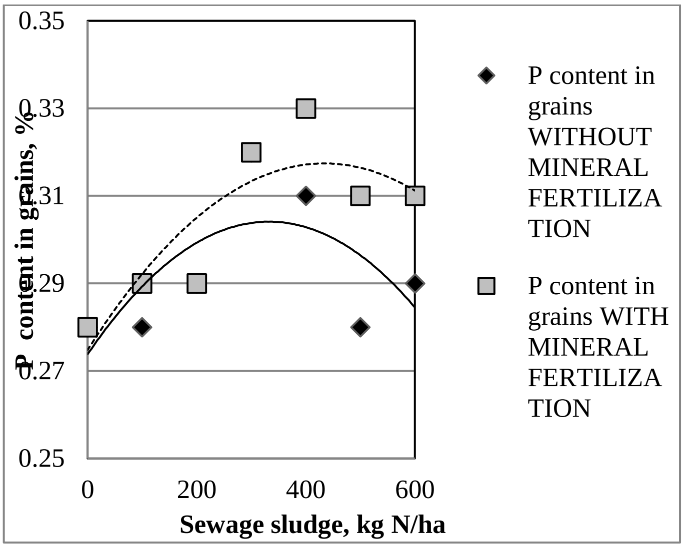

Figure 2. Correlation between phosphorus content in grains and applied nitrogen doses (** strong correlation, 0.001 < p <0.01)

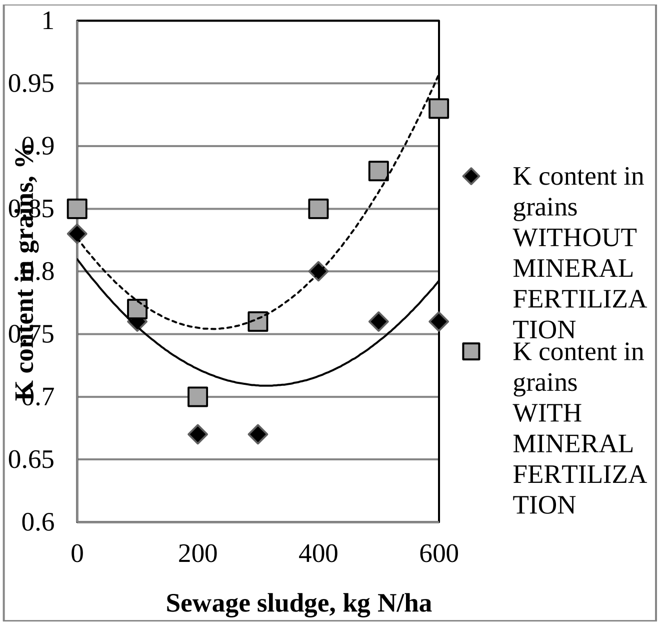

Figure 3. Correlation between potassium content in grains and applied nitrogen doses (** strong correlation, 0.001 < p <0.01)

3.4. Influence of sewage sludge application on Ca and Mg contents in grains

Calcium contents in oat grains present a significant increase after fertilization with sewage sludge, the values being statistically assured after application of a dose equivalent with 400 kg N/ha. At a dose equivalent with 600 kg N/ha, the calcium levels (0.24%) increased 3 times in comparison with untreated variant (0.08%) (table 6). Mineral fertilization, accompanied or not by organic fertilization did not led to significant changes of calcium in oat grains, the obtained values being similar with those obtained after organic fertilization.

Similar calcium levels were reported by Jakobsone et al. for oat grains [31, 32]. Del Coco et al. found the same calcium levels in wheat grains [30].

Fertilization with sewage sludge, associated or not with mineral fertilizers, did not produced significant changes of magnesium levels in oat grains, found concentrations being considered as normal values and in agreement with those reported for cereal grains [29].

Table 6. Influence of sewage sludge application (without/with mineral fertilization) on Ca and Mg contents in grains

Sewage sludge		Ca,%			Mg, %		
		b_1	b_2	Av. (b)	b_1	b_2	Av. (b)
a_1	0 kg N/ha	0.09	0.07	0.08a*	0.24	0.22	0.23a*
a_2	100 kg N/ha	0.10	0.10	0.10a	0.23	0.24	0.24a
a_3	200 kg N/ha	0.13	0.11	0.12ab	0.25	0.23	0.24a
a_4	300 kg N/ha	0.12	0.12	0.12ab	0.24	0.24	0.24a
a_5	400 kg N/ha	0.15	0.19	0.17bc	0.24	0.27	0.26a
a_6	500 kg N/ha	0.18	0.20	0.19cd	0.26	0.28	0.27a
a_7	600 kg N/ha	0.24	0.23	0.24d	0.25	0.27	0.26a
Av. (a)		0.14a*	0.15a	-	0.24a*	0.25a	-

b_1 - corresponds to $N_0P_0K_0$ (without mineral fertilization), b_2 - corresponds to $N_{100}P_{100}K_{100}$ (mineral fertilization)
Av. - average
*Mean values accompanied by same letter (a or b) does not present significant differences (Tukey multiple comparison test - significance level 0.05)

The content of calcium in oat grains correlates statistically very strong with nitrogen doses corresponding to the application of sludge in experimental variants with/without mineral fertilization (Figure 4). The magnesium content in grains correlates statistically strong with nitrogen doses from variants with mineral fertilization and for those without mineral fertilization the coefficient reveals statistically a not- significant correlation (Figure 5).

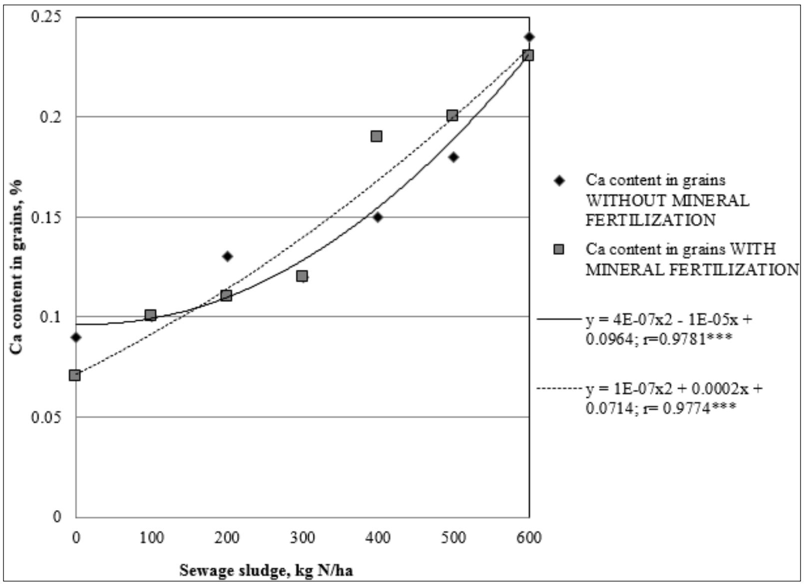

Figure 4. Correlation between calcium content in grains and applied nitrogen doses (*** very strong correlation, p<0.001)

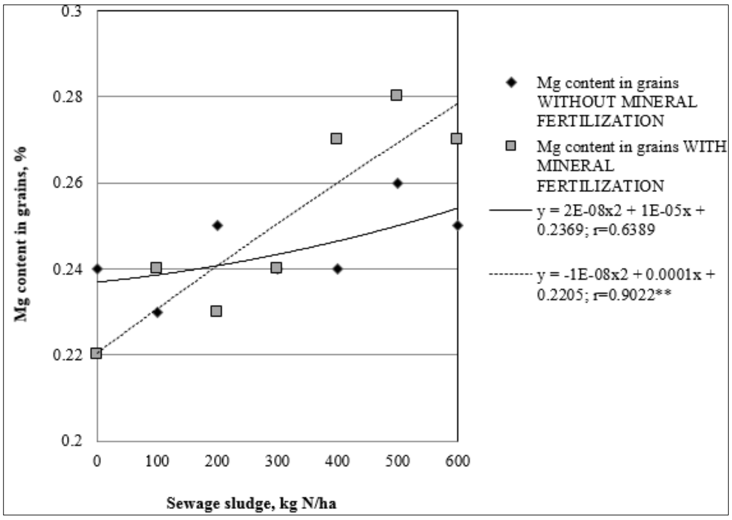

Figure 5. Correlation between magnesium content in grains and applied nitrogen doses (** strong correlation, $0.001 < p < 0.01$)

4. Conclusions

Based upon the findings of this study, the main conclusions are presented below.

Starting with equivalent dose of 100 kg N/ha, sewage sludge application produce significant increase of plant height. The highest height was recorded in the case of doses equivalent with 300 and 400 kg N/ha.

Grains yields increase significant with sewage sludge application, the highest value, as average being obtained for sewage dose equivalent with 500 kg N/ha and 600 kg N/ha. Mineral fertilization led to significant oat grains yield in comparison with unfertilized variant. Also, straw yield increased with sewage sludge doses.

Sewage sludge application associated with mineral fertilizers does not provide significant statistical increases of grains yield and straw yield but these parameters are slightly higher in comparison with the variants fertilized organic only.

Nitrogen contents in oat grains increases with applied sewage sludge dose, being significant from an equivalent dose of 200 kg N/ha. No significant changes were recorded for phosphorus levels in oat grains in the case of sewage sludge application, associated or not with mineral fertilizers.

At low sewage sludge doses equivalent with 200-300 kg N/ha, potassium concentration in oat grains after sewage sludge application present a significant decrease in comparison with untreated variant.

Calcium contents in oat grains present a significant increase after fertilization with sewage sludge, the values being statistically assured after application of a dose equivalent with 400 kg N/ha.

Organic fertilization accompanied or not by mineral one, did not led to significant changes of calcium and magnesium in oat grains.

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