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RESIDUAL EFFECTS OF FERTILIZATION WITH SEWAGE SLUDGE COMPOST ON CROPLAND

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Abstract

Composting municipal sludge is an ecological and economic efficient technology to exploit such residual organic products in order to increase agricultural yields and soil fertility.
This study aimed to determine the improve of some chemical characteristics of soil after fertilization with composted sewage sludge associated or not with mineral fertilization after two years of application and the yields recorded after the first two years of treatment.
The experimental field was organized using subdivided parcels method, studying two gradients: organic and mineral fertilization. Before application on land as organic fertilizer, chemical characteristics of compost were analyzed in laboratory. Also it was made a characterization of soil from experimental field before and after compost fertilization.
In the first year of experimentation the highest soybean yield were recorded in variants with maximum dose of mineral fertilizer. The highest maize yield was obtained in the most intensive fertilization treatment of our experiment which consist of doses of compost equivalent to a nitrogen rate of 400 kg/ ha and mineral fertilization ($N_{100}P_{100}$).
In the second year of experimentation we recorded significant increase yields at oat crops in variants with fertilization in maximum doses. Related to soybean crops, in this second year, the values of yields were increased only in organic or mineral fertilization, but not in association of them.
Fertilizing with sewage sludge does not replace the chemical fertilization, but is used in association with it in order to satisfy the necessity of crops for the nutrients.

Key words: *fertilization, sewage sludge, yields.*

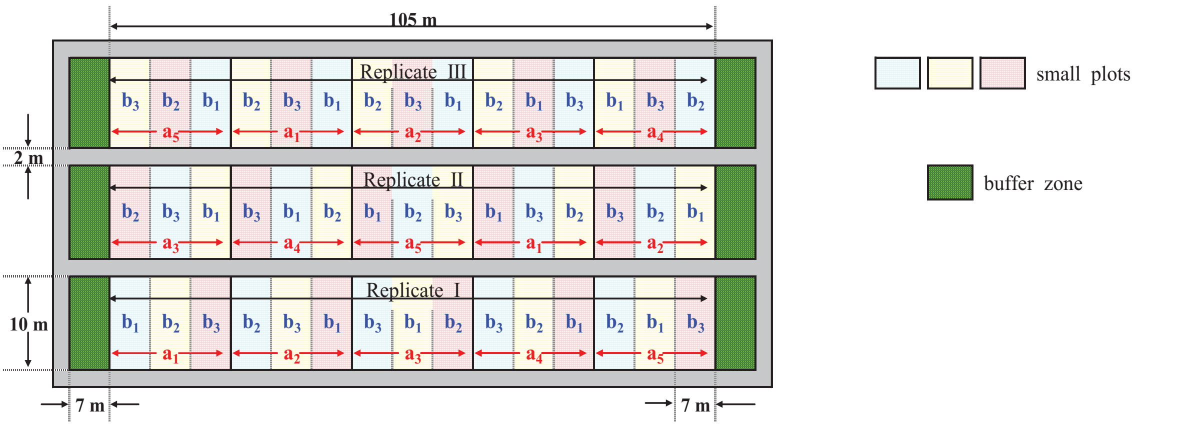
INTRODUCTION

As a result of growing population correlated with developing industry, there are some aspects which lately are taken into consideration. One of them is related to the increasing necessity of food supply and the other is the disposal of sewage sludge in order to minimize the environmental impacts. (Praspaliauskas and Pedišius, 2017).
According to the report by Mininni et al. (2015), the current production of sewage sludge in the 15 member states is estimated in about 25 kg/(P.E. x year) i.e. 68 g/(P.E. x d).
In many countries from Europe (Belgium, Netherlands, Switzerland) the incineration of sewage sludge is a predominant practice for sludge disposal and the agricultural use of ash is rarely practiced (Mininni et al., 2015).
The use of sludge in agriculture is an old, preferred alternative when it comes to disposal of these urban organic residues in some countries like France, Spain and UK (Leonard et al., 2007). In our country, just like in Greece and Malta, landfilling is still considered a solution for sludge disposal, the soil is considered in this case as a final purification step, being not only capable to offer a treatment for sludge but also to recycle nutrients for different crops (Mininni et al., 2015).
Composting is a way of processing municipal sludge in order to obtain a material sanitized and stabilized with value as bio-fertilizer for soil. Sludge and compost made from it, have a significant content of nitrogen, phosphorus and organic matter and can be an important source of nutrients for different types of crops.
In this context, the paper aimed to present the effect of different rates of sewage sludge compost associated or not with mineral fertilization on soil fertility and crop yields after two years of experimentation.

Vaca-Paulin et al. (2006) consider that sewage sludge is often composted prior to application to the agricultural soils, in order to reduce metal availability, to eliminate pathogens and to obtain an adequate product for agriculture.
Wei and Liu (2005) show that the application of composts to cropland has many advantages which include providing a large array of nutrients to the soil and reducing the need for fertilizer and pesticides.
Data from the literature (Kirchmann et al., 2017) recommend the use of sewage sludge, as a source of nitrogen and phosphorus, these being considered the most valuable nutrients in this type of compost.
The main plant nutrient present in sewage sludge is phosphorus. The concentrations of phosphorus in sewage sludge ash (7-13%), considering the trend for combustion of urban wastes, are similar to those in apatite (12-16%). This makes P recovery from ash highly relevant (Kirchmann et al., 2017).

MATERIALS AND METHODS

The experiments were organized in experimental field at Albota, on Haplic Luvisols, using subdivided parcels method, studying the two gradients: A factor – organic fertilization in 5 doses (unfertilized, 100 kg N/ha, 200 kg N/ha, 300 kg N/ha, 400 kg N/ha) and B Factor – mineral fertilization, 3 doses (unfertilized, $N_{50}P_{50}$, $N_{100}P_{100}$).
The experimental design of the experience is shown in Figure 1.
The soil in experimental field is compacted, with poor water circulation possibility on profile and low fertility.
All samples (soil, compost) were air-dried; milled in mill ground (soil) or an agate mortar (compost), homogenized and sieved to < 2 mm prior to the chemical analysis.
The pH - was measured in water suspension with a 1:2.5 soil: water suspension ratio (w:w) after 120 min equilibrium time (potentiometric method).
Organic carbon content ($C_{org)}$ was determined by sulfochromic oxidation - Walkley-Black method (dichromate oxidation followed by titration with Mohr'salt.
Total N was determined by the Kjeldahl digestion-distillation procedure.
Phosphorus (P) was determined colorimetric as molybdenum blue complex (UV/VIS spectrometry) and potassium (K) by flame photometry (Egnèr-Riehm Domingo extraction method - with ammonium acetate lactate at pH 3.75).



Type of experience: Bifactorial experience (5×3) Experimental design: Subdivided parcels method Number of replicates: 3

A Factor: Compost fertilization a_1 – unfertilized
a_2 – Compost fertilization equivalent to a N rate of 100 kg N / ha
a_3 – Compost fertilization equivalent to a N rate of 200 kg N / ha
a_4 – Compost fertilization equivalent to a N rate of 300 kg N / ha
a_5 – Compost fertilization equivalent to a N rate of 400 kg N / ha

B Factor: Mineral fertilization (N, P) b_1 - unfertilized b_2 - $N_{50}P_{50}$ b_3 - $N_{100}P_{100}$

Figure 1. Experimental design of experience organized on Haplic Luvisols to study the effects of composted sewage sludge and mineral fertilizers

Soil test data for the experimental site prior to fertilization are presented in (Table 1).

Table 1. Chemical characteristics of the soil in the experimental field (dry weight)

Depth (cm)	pH	Corg (%)	Nt (%)	P (mg/kg)	K (mg/kg)
0-27	4.67	1.57	0.10	48	57
37-36	5.59	0.76	0.07	5	67
36-44	5.37	0.49	-	4	73

For composting, sewage sludge was mixed with wheat straw or chopped stalks of peas or soybean (size of 2-5 cm) for better aeration of composting heap (of approximately 6x3x2 m^3 volume). Compost was obtained through a process of thermophilic digestion and microbial synthesis of organic substances from waste products. It was added selected microbial cultures to rise rapidly the temperatures over 60°C in order to kill pathogens from their vegetative stage.
Total heavy metals content in compost samples were measured by flame atomic absorption spectrometry (AAS) after extraction by the aqua regia - microwave digestion method. Microwave digestion was performed using 10 mL of aqua regia (7.5 mL HCl and 2.5 mL HNO_3) at 140°C for 30 min. The general properties of compost are shown in Table 2.

Table 2. Properties of compost*(dry weight)

	Min	Max	Mean
pH	7.05	7.08	7.07
Corg (%)	16.77	19.55	18.38
Nt (%)	2.07	2.4	2.24
P (%)	1.25	1.34	1.29
K (%)	0.25	0.35	0.30
Cu (mg/kg)	129	131	130
Zn (mg/kg)	1355	1381	1367
Pb (mg/kg)	76	87	80
Ni (mg/kg)	24	31	27
Mn (mg/kg)	339	350	345
Cd (mg/kg)	3.9	4.4	4.2

*the number of test samples for compost was 10

For mineral fertilization it was used urea as a source of nitrogen (46% N) and concentrated triple superphosphate as a source of phosphorus (45% P_2O_5).
Test crops were soybean (Atlas variety), maize (Turda 200 hybrid) and oat (Someşean variety).
Processing of experimental data was performed using analysis of variance and Tukey test.

RESULTS AND DISCUSSIONS

Data from Table 2 show that considering the heavy metals content in compost or their availability for crops, none of the metals analyzed had values above the permissible limits, according to Order 344/ 2004 (for the approval of the Technical Norms on environmental protection and especially of soils, when using sewage sludge in agriculture).
It can be appreciated that there are no restrictions in using this sewage sludge compost on cropland, its elemental composition recommend its application on soils with low content of microelements.
On the other hand, the high pH values of compost, usually lower the bioavailability of heavy metals and, consequently, their uptake by plant roots (Gattullo et al., 2017).
In our case, the fertilization with compost led to decreasing soil acidification because the treatment of sludge was made with lime (Table 3).
The same situation was noticed in Pennsylvania, where the use of biosolids it has been a practice since mid -1970s. The study was carried out on 20 farms and it was noticed that the pH increased by an average 0.2 pH on soils that received biosolids. The reasons of this increasing was attributed to the treatment plant of sewage sludge and to regulations which require soil pH to be at least 6.0 when biosolids are applied (http//extension.psu.edu/effects-of biosolids-on soil-and-crop-quality).
Sewage sludge composted can be a good source of nutrient for plant depends on their origin, the characteristics of the compost and the environmental regulations of the area where these will be applied.
Kominko et al. (2017) noticed that many researchers reported positive effects of using sewage sludge in agriculture by improving the physicochemical properties of soil.
This observation is consistent with Singh and Agrawal (2011) and Mi et al. (2016), quoted by

Khaliq (2017) that the organic fertilization led to increasing values of organic carbon in soil compared with mineral fertilization with NPK. Consequently, carbon content in the soil would be expected to increase as a result of organic fertilization but, in our experiment, the content of organic carbon in soil has not changed statistic significantly after treatments applied, because of clay soil texture and short time of experimentation (Table 4).

Kominko et al. (2017) also reported that meteorological factors and the type of soil have a significant influence of nitrogen uptake.

Table 3. Effects of organic, mineral and mixed fertilization on pH values in soil

Mineral fertilization	Compost fertilization										Mean value	
	Unfertilized		Compost fertilization equivalent to a N rate of:								mineral	
	with compost		100 kg/ha		200 kg/ha		300 kg/ha		400 kg/ha		fertilization	
Unfertilized	5.01		5.14		5.14		5.51		6.09		5.38	A(1)
N_{50} P_{50}	4.74		5.07		5.07		6.07		6.06		5.40	A
N_{100} P_{100}	4.69		4.91		4.92		6.26		6.48		5.45	A
Mean value compost fertilization	4.81	W(2)	5.04	W	5.04	W	5.95	X	6.21	X		

(1) or (2) - Values followed by the same letter (A, B, C or W, X, Y) are not significantly different at the p=0.05

Table 4. Effects of organic, mineral and mixed fertilization on organic carbon content in soil

Mineral fertilization	Compost fertilization										Mean value	
	Unfertilized		Compost fertilization equivalent to a N rate of:								mineral	
	with compost		100 kg/ha		200 kg/ha		300 kg/ha		400 kg/ha		fertilization	
	-- % ---											
Unfertilized	1.57		1.67		1.56		1.79		1.59		1.64	A(1)
N_{50} P_{50}	1.63		1.62		1.67		1.51		1.61		1.61	A
N_{100} P_{100}	1.54		1.61		1.63		1.62		1.58		1.60	A
Mean value compost fertilization	1.58	W(2)	1.63	W	1.62	W	1.64	W	1.59	W		

(1) or (2) - Values followed by the same letter (A, B, C or W, X, Y) are not significantly different at the p=0.05

The same (with organic carbon content in soil samples after fertilization) was the behavior of total nitrogen soil content, which has not changed statistic significantly, also (Table 5).

Kahliq et al. (2017) showed that the statistical analyses of TN% (total nitrogen) in soil sample among all treatments (Kala compost-commercial name of the organic fertilizer produced from municipal sewage treated wastewater and mineral fertilizers with three elements - NPK) was not significant.

Vieira R. et al. (2014) emphasized that the dynamics of nitrogen applied with the sludge is complex and demands studies in the sense of evaluating the amount of sludge to be applied to the soil and the frequency of application.

Beside nitrogen, utilization of sewage sludge in agriculture has a major interest due to phosphorus and potassium supply.

Zaman et al. (2002) quoted by Mtshali et al. (2014) consider that treated sewage sludge can enrich soil with macronutrients such as phosphorus and potassium. Nyamangara and Mzezewa (2001) quoted by Mtshali J. (2014) reported that phosphorus increase was observed from control plot where phosphorus content in soil was about 2-4 mg/kg to 29-114 mg/kg of phosphorus in sludge amended soil.

Table 5. Effects of organic, mineral and mixed fertilization, on total nitrogen content in soil

Mineral fertilization	Compost fertilization										Mean value	
	Unfertilized		Compost fertilization equivalent to a N rate of:								mineral	
	with compost		100 kg/ha		200 kg/ha		300 kg/ha		400 kg/ha		fertilization	
	---------- % ----------											
Unfertilized	0.146		0.160		0.151		0.164		0.161		0.156	A(1)
N_{50} P_{50}	0.153		0.156		0.170		0.143		0.157		0.156	A
N_{100} P_{100}	0.147		0.151		0.158		0.153		0.161		0.154	A
Mean value compost fertilization	0.149	W(2)	0.156	W	0.160	W	0.153	W	0.160	W		

(1) or (2) - Values followed by the same letter (A, B, C or W, X, Y) are not significantly different at the p=0.05 level

In our experiment the organic fertilization with the highest dose of compost equivalent to 400 kg N/ha led to statistically significant increases of mobile phosphorus content in soil. Also, we recorded increases of mobile phosphorus content in soil at doses of compost equivalent to 100, 200 and 300 kg N/ha, but these are not statistically significant (Table 6). Similar results was obtained from experimental field in Pennsylvania and the reason could be the fact that biosolids phosphorus is held strongly in soil and it is necessary repeatedly applications of biosolids over several years for increasing soil test levels (http//extension.psu.edu/effects-of biosolids-on soil-and-crop-quality).

He et al. (2001), quoted by Diacono and Montemurro (2009), reported that the biosolids-municipal solid waste co-compost applied, once at 4 years, has also been found to effectively supply P to soil at 0-15 cm depth.

Table 6. Effects of organic, mineral and mixed fertilization on mobile phosphorus content in soil

Mineral fertilization	Compost fertilization										Mean value	
	Unfertilized		Compost fertilization equivalent to a N rate of:								mineral	
	with compost		100 kg/ha		200 kg/ha		300 kg/ha		400 kg/ha		fertilization	
	---------- mg / kg ----------											
Unfertilized	33		37		41		42		48		40	A(1)
N_{50} P_{50}	43		42		43		45		50		45	A
N_{100} P_{100}	35		38		39		50		49		42	A
Mean value compost fertilization	37	W(2)	39	WX	41	WX	46	WX	49	X		

(1) or (2) - Values followed by the same letter (A, B, C or W, X, Y) are not significantly different at the p=0.05 level

Concerning potassium, as a water-soluble nutrient, the concentrations in sewage sludge are lower than in other organic amendments (such as manures) (Kirchmann et al., 2017). On the other hand, in our experiment (Table 7), the lack of potassium from mineral fertilizer recipe explains the absence of significantly changes of the mobile potassium content in the soil.

Consequently, compared with the check (unfertilized variant), the content of mobile potassium in soil did not change significantly after compost application or mineral fertilization.

The average values of potassium content in soil ranged between 85 mg/kg - 94 mg/kg.

Generally, the data from literature demonstrated that organic amendments long-term applications enhanced soil available potassium, extractable phosphorus and organic carbon content (Diacono and Montemurro, 2009).

The use of biosolids on Pennsylvania cropland, in a three year research project, showed even lower soil test potassium level in biosolid fields than they were in control fields. It was considered that the amount of potassium added by biosolid it was not sufficient to fulfill the crop necessity. Alternative source of potassium should be considered (chemical fertilizer or manure) to maintain optimum potassium soil test levels (http//extension.psu.edu/effects-of biosolids-on soil-and-crop-quality).

The use of quality compost is a sure way of restoring organic matter to the soil, mitigation of acute tendency of decreasing soil nutrient reserves and a way to increase the crops quality.

Evaluating the quality compost is done not only by laboratory tests, but also in experimental field.

Because the sewage sludge compost used in our experimental field contain low levels of nutrients compared with mineral fertilizer and it is known that the low mineralization rates did not satisfy the requirements of a crop, we studied the combined effects of applying compost and mineral fertilizers (N-P). On the other hand, by applying compost it is expected to increase recovery ratios of nutrients from mineral fertilizers.

We tried to obtain economic efficiency of using compost by careful choice of crop rotation and monitoring of the environment.

Table 7. Effects of organic, mineral and mixed fertilization on mobile potassium content in soil

Mineral fertilization	Compost fertilization										Mean value	
	Unfertilized		Compost fertilization equivalent to a N rate of:								mineral	
	with compost		100 kg/ha		200 kg/ha		300 kg/ha		400 kg/ha		fertilization	
	mg / kg											
Unfertilized	85		79		85	a	94	a	88	a	86	A(1)
N_{50} P_{50}	88		85		85	a	85	a	88	a	86	A
N_{100} P_{100}	85		85		91	a	85	a	88	a	87	A
Mean value compost fertilization	86	W(2)	83	W	87	W	88	W	88	W		

(1) or (2) - Values followed by the same letter (A, B, C or W, X, Y) are not significantly different at the p=0.05 level

The data from the first year of experimentation show that the soybean yield increased statistically significant with the increases of mineral fertilizer doses from 789 kg/ha to 1043 kg/ha (Table 8). The increase of compost dose led to a slightly decrease of soybean yield, probably because of heavy metals content from sewage sludge, who reduced the nitrogen-fixing microorganisms activity. As soybean plant has a high demand of nitrogen, the decline of the nitrogen content in the soil due to the lack of symbiotic microorganisms has resulted in a diminished yield of soybean crop.

Noggle and Fritz (1976), quoted by Kabir et al. (2011) appreciate that optimum dose of essential nutrient elements ensure the highest yield of a crop.

In this sense, by supplying nutrient from sewage sludge, Lavado (2006), quoted by Kabir et al. (2011), found increased yield of sunflower.

Table 8. Effects of organic, mineral and mixed fertilization on soybean yield

Mineral fertilization	Compost fertilization										Mean value	
	Unfertilized		Compost fertilization equivalent to a N rate of:								mineral	
	with compost		100 kg/ha		200 kg/ha		300 kg/ha		400 kg/ha		fertilization	
	--- kg / ha ---											
Unfertilized	609		906		831		750		847		789	A(2)
N_{50} P_{50}	872		958		926		857		871		897	B
N_{100} P_{100}	1378		976		1028		932		903		1043	C
Mean value compost fertilization	953	W	947	W	928	W	846	X	874	X		

(1) or (2) - Values followed by the same letter (A, B, C or W, X, Y) are not significantly different at the p=0.05 level

In Pennsylvania project where biosolids were used as a nitrogen fertilizer, there were no differences in crop yields between biosolids and control fields (control fields used conventional chemicals fertilizers and manures) (http//extension.psu.edu/effects-of biosolids-on soil-and-crop-quality).

Considering maize crop, in our experiment, the association between organic and mineral fertilization (N-P) was beneficial for maize yield, possibly due to high maize tolerance for heavy metals (maize is considered a plant that can be cultivated on land fertilized with high doses of sewage sludge).

The results suggested that the compost application associated or not with mineral fertilization generated positive yield responses (Table 9). Wei and Liu (2005) observed that compared with the check, the compost application increased significantly the weight of barley spikes and grains and the mean weight and yield of Chinese cabbage.

Table 9. Effects of organic, mineral and mixed fertilization on maize yield

Mineral fertilization	Compost fertilization										Mean value	
	Unfertilized		Compost fertilization equivalent to a N rate of:								mineral	
	with compost		100 kg/ha		200 kg/ha		300 kg/ha		400 kg/ha		fertilization	
	--- kg / ha ---											
Unfertilized	6449		8207		8609		8621		9753		8328	A(2)
N_{50} P_{50}	7554		8750		8636		9354		9939		8847	B
N_{100} P_{100}	8432		9335		9404		9542		10090		9361	C
Mean value compost fertilization	7478	W	8764	X	8883	X	9172	Y	9927	Z		

(1) or (2) - Values followed by the same letter (A, B, C or W, X, Y) are not significantly different at the p=0.05 level

The maize yield in our experiment increased statistically significant with the dose of mineral fertilizer from 8328 kg/ha in unfertilized plot to 9361 kg/ha after mineral fertilization in high dose ($N_{100}P_{100}$). Compost fertilization equivalent to increasing rate of nitrogen led also to statistically significant increases of maize crop, from 6449 kg/ha in unfertilized plot, to 9753 kg/ha in plots fertilized with composted sewage sludge equivalent to a N rate of 400 kg/ha.

In the second year of experimentation, the oat yields increased statistically significant with the doses of mineral fertilizer (N-P) or with the increasing doses of organic fertilizer (Figure 2). The most benefit for the yield increment was the use of combined fertilization in highest doses ($N_{100}P_{100}$ and compost at dose equivalent to 400 kg N/ha).

Cherif et al. (2009), quoted by Diacono and Montemurro (2009) obtained also enhanced wheat grain yield on average by 246% in respect to the control, with a high rate (80 t/ha) of municipal solid waste compost applied annually over 5 years, alone or combined with mineral fertilizer.

Regarding soybean yield in second year, the dates highlights that the mineral fertilizer was more beneficial for the yield of soybean (it was obtained an increasing of 56% related to unfertilized control), compared with compost fertilization (the increasing was about 40% related to unfertilized control) (Figure 3).

The combination of the two type of fertilization in a drought year has not led to large increases of soybean crop production and it is explained by the high water demand of this plant.

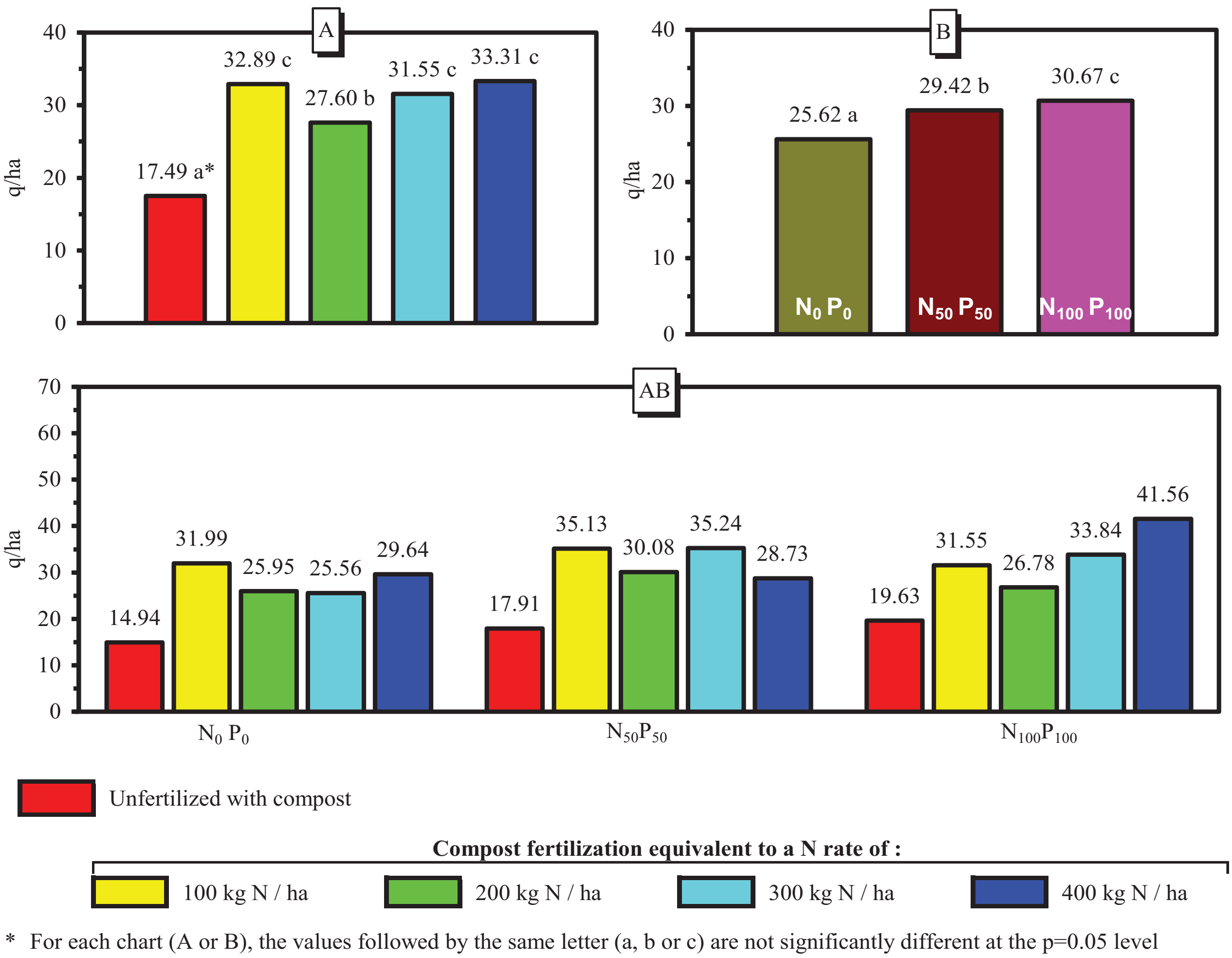


Figure 2. Effects of organic (A), mineral (B) and mixed fertilization (AB) on oat yield

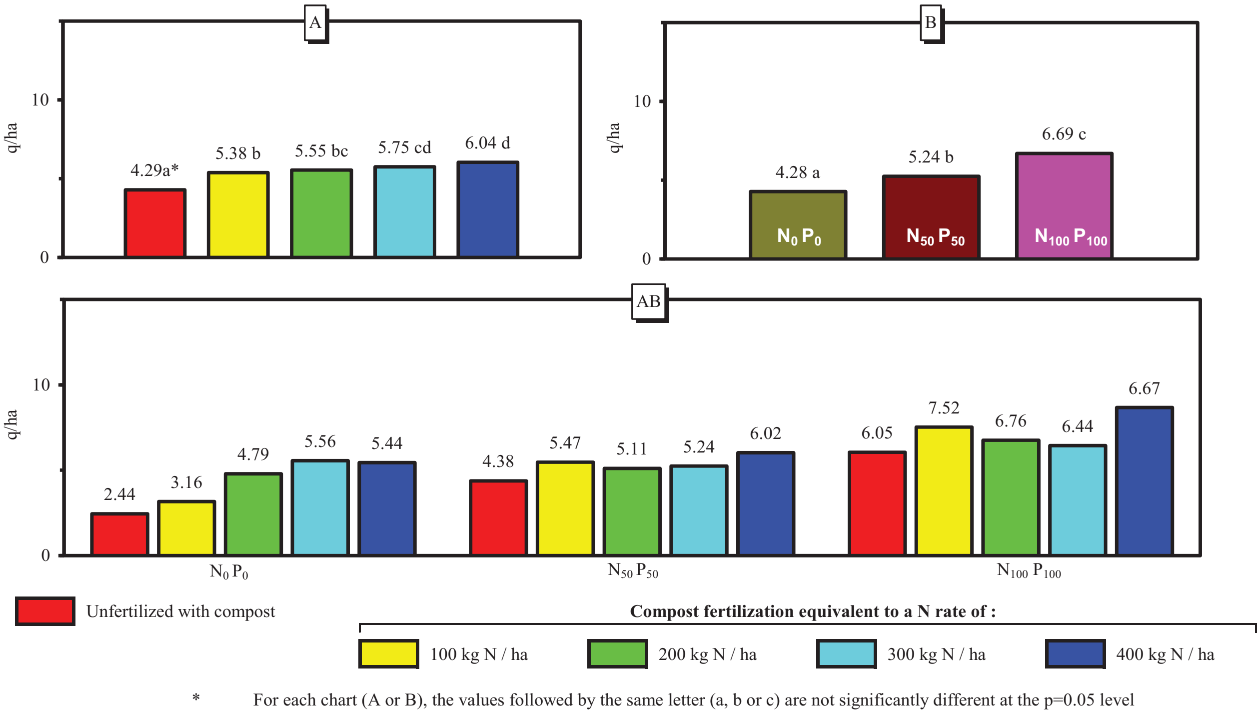


Figure 3. Effects of organic (A), mineral (B) and mixed fertilization (AB) on soybean yield

CONCLUSIONS

Following municipal sludge composting process are obtained materials that can be used beneficially as bio-fertilizers and conditioning of soil. Application of compost on cropland will take into account the characteristics of compost and soil, the plant needs and the environmental regulations from area. The fertilization with sewage sludge compost does not replace chemical fertilizer but is applied along with it to fulfill necessary nutrients for plants. The experimental results in this paper showed that compost fertilization associated with mineral fertilization led to better yields responses for oat, maize and soybean comparing with only one type of fertilization.

Mineral fertilization of soils is a short-term solution in terms of increasing yield but the alternative of applying composted sewage sludge could lead to a nutrient slow-release effect.

On the other hand a reliable agronomic value of organic amendments can be determined over years of application on soils considering the climate, soil type and compost characteristics. Long time research on sewage sludge compost as amendment on cropland is particularly relevant, because the composition of compost can influence the soil fertility and the potentially accumulation of heavy metals in soil, but these changes evolve slowly.

To predict the effects of applying different organic amendments is useful to continue the research in order to establish the most appropriate technologies for sewage sludge composting, as it is known that composting process reduce the heavy metal availability.

Another aspect for which continued long-term research could be important is the recommendation of optimal doses mixed with mineral fertilizers to obtain high crop yields.

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