Hungarian University of Agriculture and Life Sciences (MATE)

EVALUATION OF AGRICULTURAL UTILIZATION OF COMMUNAL SEWAGE SLUDGE COMPOST IN A LONG TERM FIELD EXPERIMENT

Theses of doctoral (PhD) dissertation

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1. THE BACKGROUND AND OBJECTIVES OF STUDY

The level of domestic nutrient supply is far below that of the 1970s and 1980s. Currently, 110-120 kg ha^{-1} of nutrients are applied on average to cultivated land in our country. This contributes to the decline in soil nutrient content, which is further exacerbated by the gradual increase in input prices, so that the vast majority of farmers apply only one-sided, limited amounts of nutrients (mainly nitrogen).

In order to confirm the former assumption and to dispel doubts in farmers planning to use sewage sludge compost of municipal origin, it is important to study sewage sludge composts in the long term. If the results confirm the positive effect of sewage sludge compost on soil chemistry and crop quality parameters, then it is safe to use these products to replenish the macro- and microelements and, above all, the missing organic matter in our soils.

My work at the University of Debrecen CAS Research Institute of Nyíregyháza was carried out in a unique way in Hungary in a small-plot experiment based on composted sewage sludge as a source of nutrients and organic matter, where I measured the questions concerning the tank effect of sewage sludge compost. I studied the effects of sewage sludge compost on soil and plants in arable land.

In writing my thesis, I was looking for answers to the following questions:

- To what extent does the treatment of municipal sewage sludge compost over several years affect the yield of the test crops used.

- How long-term compost treatment affects these parameters among the soil chemical properties investigated in field experiments.
- How sewage sludge compost treatment affects the relationship between soil pH and yield of test crops.
- Besides its impact on the soil, what is the effect of regular compost application on the element content of plants.

2. MATERIALS AND METHODS

2.1. Design of the experiment

The small plot experiment was located at the Research Institute of Nyíregyháza, on plot 0414/a lot number, with the following GPS coordinates: N; 47^{o}98'69, E; 21^{o}70'23. The experiment was established in spring 2003 using the compost preparation NYÍRKOMPOSZT, developed in collaboration with Nyírségvíz Ltd. In a unique way in Hungary, we maintain the area as a small-plots experiment based on composted sewage sludge as a source of nutrients and organic matter, where sewage sludge compost is applied to the area every three years, similar to the manure used in stables.

The design of the experiment was based on four treatments in five blocks, where sewage sludge compost was spread every three years in each block at a dose of 0, 9, 18 and 27 Mg ha^{-1} of dry matter, and then ploughed into the soil layer to a medium depth (0-25 cm). In the experiment, green pea (*Pisum sativum* L.), triticale (x *Triticosecale X Wittmack*) and maize (*Zea mays* L.) test crops were rotated in a spread rotation. The layout of a block is shown *in Figure 1*.

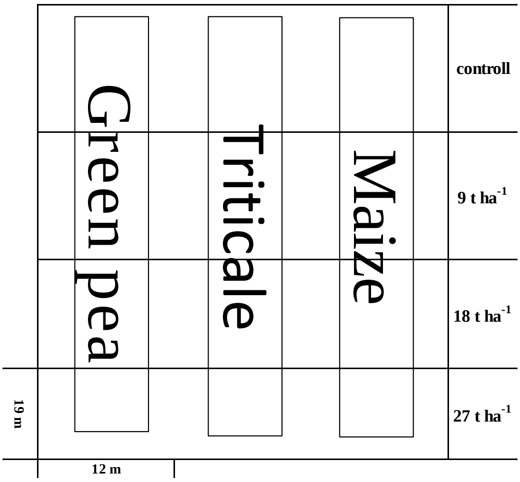

Figure 1. Arrangement of sewage sludges compost doses and tests plants in a block.

The composition of the unrestricted fertilizer (NYÍRKOMPOSZT) applied several times (2006, 2009 and 2012) was as follows: 40% wastewater sludge, 25% straw, 30% rhyolite and 5% bentonite. The compost was always applied after harvesting, preceded by testing of the quality parameters of the sewage sludge compost. Among the test crops, green pea and maize stalk residues were incorporated into the soil, while triticale straw was cut from the experimental plots every year.

2.2. Soil of experimental area

The soil of the experimental area can be classified as sand physical metallocene, based on the binding value, with acidic chemistry, medium humus and phosphorus content, and good potassium content (Makádi et al. 2008). The above findings are supported by the following parameters: pH(H_2O): 6,20; pH(KCl): 5.31; humus%: 0.90; NO_3-N – 9.6 mg kg^{-1}; P_2O_5- 240,1 mg kg^{-1}; K_2O:183,3 mg kg^{-1}. During the experimental period, a soil section pit was also dug, the examination of which showed that there were several strips of silica beneath the 40 cm layer of soil. Thus the soil type of the area is a Arenosol (Dystric Lamellic Arenosols).

2.3. Test crops used in the experiment

The cultivation techniques of the test crops used in the experimental area are summarized in *Table 1.*

Table 1. Agro-technological operations of the test crops in the sewage sludge compost experiment

plant species	**maize**	**green pea**	**triticale**	**maize**	**green pea**	**triticale**
plant variety	**MV NK 333 MTC**	**Zeusz**	**Dusi**	**MV NK 333 MTC**	**Zeusz**	**Dusi**
years	**2006**			**2007**		
work process						
preparation of seed-beds				x	x	
sowing (in spring)				x	x	
pest controll				x	x	
harvest				x	x	x
stem-crushing				x		x
disking				x	x	x
compost spilling	x	x	x			
ploughing	x	x	x	x	x	x
preparation of seed-beds						x
sowing (in autumn)			x			x
plant species	**maize**	**green pea**	**triticale**	**maize**	**green pea**	**triticale**
plant variety	**MV NK 333 MTC**	**Zeusz**	**Dusi**	**MV NK 333 MTC**	**Zeusz**	**Dusi**
years	**2008**			**2009**		
work process						
preparation of seed-beds	x	x		x	x	
sowing (in spring)	x	x		x	x	
pest controll	x	x		x	x	
harvest	x	x	x	x	x	x
stem-crushing	x		x	x		x
disking	x	x	x	x	x	x
compost spilling				x	x	x
ploughing	x	x	x	x	x	x
preparation of seed-beds			x			x
sowing (in autumn)			x			x
plant species	**maize**	**green pea**	**triticale**	**maize**	**green pea**	**triticale**
plant variety	**MV NK 333 MTC**	**Zita**	**Titán**	**MV NK 333 MTC**	**Zita**	**Titán**
years	**2010**			**2011**		
work process						
preparation of seed-beds	x	x		x	x	
sowing (in spring)	x	x		x	x	
pest controll	x	x		x	x	
harvest	x	x	x	x	x	x
stem-crushing	x		x	x		x
disking	x	x	x	x	x	x
compost spilling						
ploughing	x	x	x	x	x	x
preparation of seed-beds			x			x
sowing (in autumn)			x			x
plant species	**maize**	**green pea**	**triticale**	**maize**	**green pea**	**triticale**
plant variety	**MV NK 333 MTC**	**Zita**	**Szabolcs**	**MV NK 333 MTC**	**Zita**	**Titán**
years	**2012**			**2013**		
work process						
preparation of seed-beds	x	x		x	x	
sowing (in spring)	x	x		x	x	
pest controll	x	x		x	x	
harvest	x	x	x	x	x	x
stem-crushing	x		x	x		x
disking	x	x	x	x	x	x
compost spilling	x	x	x			
ploughing			x			x
preparation of seed-beds			x			x
sowing (in autumn)			x			x

2.4. Climatic conditions of the experimental area during the period under study

The average rainfall for the period shown was 532 mm in 2007, 561 mm in 2008 and 624 mm in 2009. The highest rainfall was in 2010 (995 mm). Precipitation typical for this part of the Plain was recorded in 2011 (454 mm), followed by very low precipitation in 2012 (382 mm). In 2013, precipitation was again around average (485 mm).

In 2007, the spring and summer were warmer than the long-term average, but from September onwards the weather was cooler than usual. In April 2009, the monthly mean temperature was 4.2 ^{o}C higher.

2010 was considered an average year in terms of temperatures. In comparison, 2011 was warmer. Summer 2012 was the second hottest summer in the last 112 years. The year 2013 was not far behind the temperatures recorded in 2012 (TOMÓCSIK, et al., 2016).

2.5. Test parameters of the compost mixture

The composition of the sewage sludge compost was prepared in compliance with the limits for composts of the currently valid Ministry of Agriculture and Rural Development Decree 36/2006 (V.18.). *Table 2* shows the test results of the birch compost applied 3 times during the period under study.

Table 2. Test results of applied compost in the years of application

Parameter	years of application		
	2006	2009	2012
pH (H_2O 1:10)	7.13	n.m.	7.18
Dry matter content [m/m% row matter]	58.49	45.88	n.m.
Organic matter content [m/m % dry matter]	25.67	20.6	27.63
Water soluble total salt [m/m% dry matter]	3.75	3.02	2.15
Total N-content [m/m% dry matter]	1.09	1.15	1.26
Total P_2O_5-content [m/m% dry matter]	2.47	2.71	1.04
Total K_2O-content [m/m% dry matter]	0.56	0.47	0.27
Total Mg-content [m/m% dry matter]	0.53	0.32	0.43
As (mg kg^{-1})	8.13	18.71	9.44
Cd (mg kg^{-1})	1.41	0.74	1.6
Co (mg kg^{-1})	5.47	2.92	3.65
Cr (mg kg^{-1})	25.70	11.17	12.67
Cu (mg kg^{-1})	93.50	110	124.67
Hg (mg kg^{-1})	0.84	0.76	<1.00
Ni (mg kg^{-1})]	31.10	9.46	8.06
Pb (mg kg^{-1})	38.10	16.04	24.5
Se (mg kg^{-1})	0.57	0.07	<1.00

2.6. Sampling methods and dates

To measure the soil properties tested, soil samples were collected from the ploughed (0-30 cm) and deeper (30-60 cm) layers, averaged per test crop and per compost dose, from five point samples taken from five samplings. Then, we homogenized the point samples in plastic buckets and collected the soil samples in nylon bags with code numbers and internal labels.

Soil sampling was carried out each year in September after harvesting, before the compost application due. Before testing, soil samples were sieved through a 2 mm sieve and stored in an air-dry condition. In 2011, soil samples from the sewage sludge composting experiment were not tested.

To evaluate the effect of sewage sludge compost on the yield of test crops, the amount of seed collected was measured (per compost bin, from each plot, after manual harvesting of green peas and triticale from 4x1 $m^2$and maize from 4x1 running metre, then processing and cleaning) and the yield per hectare (t ha^{-1}) was calculated from the results.

2.7. Test carried out on soil and plants samples

The soil chemistry tests were carried out by the Laboratory of the MÉK Agricultural Centre of the University of Debrecen, according to the following standards: **pH(KCl**) - MSZ08-0206-2:1978; **pH(H_2O)** - MSZ-08-0206-2:1978; **humus(%)** - MSZ-08-0210:1977; **AL-soluble P_2O_5**(mg kg^{-1}) - MSZ 20135:1999; **AL-soluble K_2O** (mg kg^{-1}) - MSZ 20135:1999; **KCl EDTA-soluble Cu** (mg kg^{-1}) - MSZ 20135:1999; **KCl EDTA-soluble Zn** (mg kg^{-1}) - MSZ 20135:1999; **total Cu** (mg kg^{-1}) in soil - MSZ 20135:1999; **total Zn** (mg kg^{-1}) in soil - MSZ 20135:1999; **Total Zn** (mg kg^{-1}) **in plants** was determined according to MSZ-08-1783-33:1985 and **total Cu** (mg kg^{-1}) **in plants was** determined according to MSZ-08-1783-34:1985, also in the Laboratory of the Agricultural Engineering Centre of the University of Debrecen.

2.8. Applied statistical methods

I used the IBM SPSS Statistics 21.0 software package to evaluate the data. The effect of treatments was examined by multi-factor analysis of variance. I used Tukey's test to detect differences between treatment means, using the letters alphabet to indicate different groups. Treatment effects were tested at the 95% ($p \leq 0.05$) probability level. Pearson's correlation analysis (SAJTOS, and MITEV, 2007) was used to describe the closeness and direction of the relationships between soil chemical properties and yields of test crops.

3. RESULTS AND DISCUSSIONS

In the following, I present my results evaluated by statistical methods, where I investigated the effect of sewage sludge compost on soil chemical properties [pH(H_2O), pH(KCl), Al-soluble P_2O_5, Al-soluble K_2O, humus%, total copper (Cu) mg kg^{-1}, total zinc (Zn) mg kg^{-1}], element content in soil and test plants and yield of test plants. The results were used to monitor the changes in the soil-plant system based on the applied material and its applied doses.

3.1. Changes in soil physical properties between 2007-2013

Taking into account the soil properties, the most favourable range for the chemical reaction is around the neutral range. In acidic conditions, the uptake of nutrients important for plants is reduced, but most of the toxic and potentially toxic elements are easily absorbed in this range.

The potassium chloride pH {pH(KCl)} of soil samples from the top ploughed layer (0-30 cm) of the experimental area was positively affected by compost treatment in four of the years I studied. Also in the period from 2009 to 2013, I observed higher pH in the soil of the treated plots compared to the control and a statistically verifiable difference between the different amounts of composts.

The compost preparation, applied every three years, had a significant effect on the soil chemistry of the treated area, as the pH in the control plots dropped below pH 4 by the end of the period shown.

Based on the pH(KCl) results of the samples from the deeper (30-60 cm) soil layer of the study area, a slight increase in pH(KCl) was observed in 2007-2008 as a result of compost treatments compared to the control. From the year 2009 until the last year presented (2013), the average results of 27 t ha^{-1} were the highest.

At the beginning of the experiment (2003), I measured the soil pH in aqueous extract {pH(H_2O)} (6.20), which decreased in the control plots during the period shown, and this decrease was further enhanced until 2013, so I observed a decrease in the pH of the sandy soil even without fertilization. A statistically verifiable positive effect was observed compared to the untreated area at all three doses in 2008, 2010, 2012 and 2013. The compost applied every three years (2006, 2009 and 2012) did not increase the soil pH in aqueous extract significantly. Similar to the potassium chloride pH value, it consistently approached the neutral value.

Examining the pH(H_2O) results of soil samples taken from the 30-60 cm layer of the study area, the higher compost rates (18 and 27 t ha^{-1}) resulted in statistically proven treatment effects in 2010 and 2012. All three doses, only in 2013, could achieve such results. During the period studied, the pH did not change to the extent that was observed in the ploughed soil layer.

Examining the results of the organic matter content of the ploughed soil layer, I found higher values due to the compost treatment, but the results obtained do not mathematically justify the treatment effect in 2008 and 2009. In the last two years studied (2012-2013), all plots showed an increase in humus content as a result of compost treatments. The highest dose (27 t ha^{-1}) in 2012 and the average dose of 18 t ha^{-1} in 2013 showed a statistically proven treatment effect.

As a result of compost application in 2006, the average organic matter content in 2007 was similar to the control area in all three treatments. In the following year (2008), I measured higher average organic matter in all treatments compared to the control. In 2009, I observed a similar trend to the previous year when analysing the average values of the results. In the next observation year (2010), the 9 t ha^{-1} treatment resulted in the highest increase in organic matter content, but the other two doses also resulted in an increase in the parameter studied. In 2012, the 9 and 27 t ha^{-1} doses resulted in higher values of organic matter content compared to the control area. At the last time point tested (2013), the sewage sludge compost treatments resulted in an increase in organic matter content in the average samples from all three treated areas.

Evaluating the organic matter data of the soil samples from the deeper layer, I found that the organic matter content in this soil layer also increased, but to a lesser extent than in the cultivated layer. At the beginning of the period shown (2007), after compost application, I obtained almost identical results in the average samples collected from the control and treated areas. No statistically verifiable treatment effect could be detected in this year. I came to the same conclusion when examining the mean values of the results. The following year (2008), I observed an increase in all plots. I observed higher average values for the two higher doses (18 and 27 t ha^{-1}) compared to the lowest dose (9 t ha^{-1}), but higher average results for the control plots for all three treatments. In 2009, there was no significant increase compared to the increase in the previous year and two treatments (18 t ha^{-1} and 27 t ha^{-1} plots) showed a decrease in organic matter content. In the year following application (2010), the organic matter content in the deeper soil layer

(30-60 cm) decreased compared to the previous year, except for the 9 t ha^{-1} treatment.

In 2012, the organic matter content in the plots not receiving compost was almost the same as in the compost treatments. In the following year (2013), the different doses did not increase the value of the soil properties tested in that year.

The recoverable phosphorus content of soil samples taken from the top (0-30 cm) soil layer of the experimental area increased proportionally with the applied sewage sludge compost dose between 2008 and 2013. During this period, the AL-soluble phosphorus content of the soil increased from medium to good to very good levels as a result of the sewage sludge compost application rates. After the 2006 application, the most significant increase in the available phosphorus content, taking average values into account, was in 2007, when the 9 t ha^{-1} treatment was applied. The other two doses showed only a slight increase in the measured value compared to the control. In 2008, all three treatments also resulted in an average increase in AL-P_2O_5content. In this year, the value of the soil chemical property tested increased in the same direction as the increase in the doses applied.

Compared to the control area, the compost treatments of 18 and 27 t ha^{-1} resulted in a mathematically verifiable treatment effect. In the following year (2009), the 27 t ha^{-1} rate resulted in a more than 2.5x increase in results compared to the untreated area, showing a statistically verifiable positive effect. The 9 t ha^{-1} dose resulted in an increase of AL-P_2O in the $_5$soil of almost 50% and the 18 t ha^{-1} compost dose resulted in a 90% increase. I observed a similar trend when evaluating the average results for the other years presented in my thesis (2010, 2012 and 2013). In all three years listed above, I measured a statistically verifiable increase in soil AL-soluble phosphorus content in response to the highest dose (27 t ha^{-1}).

Analysing the results of the average values of AL-soluble $P_2 O_5$ content of the samples taken from the deeper (30-60 cm) soil layers of the experimental area, in 2007, the 27 t ha^{-1} compost rate improved the soil chemistry of the treatments tested. Soil from the other two dosage plots showed almost identical results, which were below the results from the untreated area. In 2008, the 18 and 27 t ha^{-1} doses were able to increase the average value of AL-soluble P content compared to the control area. The results from plots receiving the lowest compost rate (9 t ha^{-1}) were slightly lower than those from plots not receiving compost. In the next study year (2009), all treatments increased the parameter compared to the untreated area. In 2010 and 2013, a similar trend was observed as an effect of compost application. In 2012, the average values of AL-soluble P_2O_5content showed a statistically verifiable increase with the 18 t ha^{-1} dose.

In 2007, the AL-soluble potassium supply level of the experimental site was classified as good to very good. Compared to the baseline year, a significant decrease was observed in all applied doses and in the control plot. This trend showed a positive change only in 2013. The AL-soluble potassium content of soil samples taken from the deeper layer started from the lower quantitative level and decreased by the end of the study years, and sewage sludge compost treatment could not increase this test parameter.

The average amount of Cu that was applied with compost in 2006: 1.68 kg^{-1} t; in 2009: 1.98 kg^{-1} t; in 2012: 2.24 kg^{-1} t. The regular (every three years) application of sewage sludge compost resulted in an increase in the ploughed layer of the soil at the end of the period studied.

Based on the results of soil samples from the deeper (30-60 cm) soil layer of the experimental area, I can draw a very similar conclusion to the ploughed layer in this case.

In the ploughed soil layer, compost treatments in 2010 increased the amount of Cu available for soil uptake. At that time, all three doses had a positive effect on the amount of the microelement presented compared to the control. Lower values were again observed in the following years. In the deeper soil layer (30-60 cm) of the sewage sludge compost tank experiment, similar results to the upper layer were observed in the Cu uptake as a result of the treatments.

As with copper, I observed treatment effects for zinc in the ploughed and deeper soil levels tested, with higher values in the treated areas in 2009 compared to the control. I observed a similar trend in the following study year (2010). In 2012, I measured the lowest Zn in the 9 t ha^{-1} treatment. I observed statistically verifiable differences in this year compared to the control in the 18 and 27 t ha^{-1} treatments. In the last year presented (2013), samples from untreated plots gave the highest values, with lower values from the other treated plots. I also measured low concentrations of zinc uptake, typical for sandy soils, which could be slightly modified by the application of sewage sludge compost.

The evolution of total Zn in the topsoil in the first year of the study (2007), the control plot had higher values compared to the other plots in the experiment. In 2009, I measured almost the same Zn concentrations in the topsoil in the 9 and 18 t ha^{-1} treatments, with slightly higher concentrations in the 27 t ha^{-1} compost treatment. After the re-treatment, the trend of the previous year was maintained, with similar concentrations for the two lower doses and high concentrations for the high dose in 2010. In the next two years presented (2012 and 2013), I was able to observe these changes. In 2013, we were able to detect a statistically verifiable difference between the control plot and the treated plot.

3.2. Changes in elemental content and yield of test crops between 2007-2013

Among the test crops, the highest Cu concentration in green pea seeds in 2007 was measured in the control plot compared to the three treatments. In the following year (2008) I observed a decrease and obtained similar results from all plots. The amount of Cu in green pea seeds increased due to the sewage sludge compost treatment applied in 2009, based on the test results of 2010. In 2013 I observed a decrease compared to the previous year, but when looking at the results for that year, the control plot had the lowest Cu concentration.

The amount of triticale seed Cu increased after both compost applications (2009 and 2012) as a result of the treatments.

An increase in Cu concentration in maize kernel was observed after application in 2012. No statistically verifiable treatment effect was observed during my Cu concentration tests.

Changes in Zn concentrations in the grain yield of test crops used in the sewage sludge compost experiment were almost identical to those measured in the seeds of green peas in 2007 and 2008 after treatment in

2006. Subsequently, the values in the seeds of crops grown in the treated plots were higher in 2009 in the 27 t ha^{-1} treatment and in 2010 in the 18 and 27 t ha^{-1} plots after spraying in 2012 and 2013 for all three doses compared to the values in the seeds of crops grown in the control area. Of the years presented, I was able to detect a statistically verifiable treatment effect between control and treated areas in green peas in 2013.

The Zn concentration of triticale seed increased in the compost treatments in all three years after spreading. No statistically verifiable treatment effect was observed in the years shown.

For the maize test crop, I did not perform statistical calculations in 2009 due to the small number of samples. In 2010, I observed higher Zn concentrations due to the two higher doses. In 2012 and 2013, all three doses resulted in an increase in Zn in the maize grain yield.

In the first three years (2007-2009), the application of sewage sludge compost in the treated plots resulted in a slight increase in yield compared to the control plot. In 2009, the treated plots with 18 and 27 t ha^{-1} yielded more triticale compared to the untreated plot. In 2010, I measured higher yields in all three treated plots compared to the control plots. The results showed a significant treatment effect on yields between the plot receiving 27 t ha^{-1} of compost and the plot not receiving compost.

In 2011 and 2012, the yield of the test plot was higher under sewage sludge compost doses compared to the untreated plot. In these years, the amount of triticale produced at the two higher doses (18 and 27 t ha^{-1}) exceeded the amount produced in the control plots. A yield increase of more than 50% was observed in these years as a result of these treatments, which was statistically verified. The year 2013 shows proportionally similar results to the year 2010, both in terms of yield and the sum of the results between treatments, but the yield in all plots was below the previous years (2011, 2012).

The maize yield did not increase in 2007 as a result of the treatments, and the control area yielded more than the sewage sludge composted areas. In the following year (2008), all three compost doses resulted in a statistically proven increase in maize harvested compared to the untreated plot. In 2009, the 18 and 27 t ha^{-1} doses resulted in significant yield increases. In this growing season, the 9 t ha^{-1} plot yielded the least maize. In the following two years (2010- 2011), again the two higher doses (18 and 27 t ha^{-1}) had a statistically proven positive effect on maize yield. In 2012, maize yields were almost identical in untreated and treated plots. No significant difference was observed this year.

In the final year (2013), yields increased in all plots compared to the control. This increase in yield was statistically confirmed between the plot with the highest dose (27 t ha^{-1}) and the plot without sewage sludge compost.

Among the years studied, no statistically verifiable treatment effect was observed between the control and treated plots in the 2007-2008 and 2011-2013 growing seasons. Green pea yields statistically increased in 2010 as a result of sewage sludge compost application. At that time, 9 t ha^{-1} resulted in 30%, 18 t ha^{-1} in 38% and 27 t ha^{-1} in 23% higher yields compared to the control plot.

3.3. Relationship between soil physical properties and yield of test crops between study results 2007-2013

In 2007, a positive correlation was observed between triticale yield and soil potassium content in the 9 and 27 t ha^{-1} treatments and in the control plot. A similar positive correlation with a positive sign was observed for humus content in the 18 t/ha compost dose treatment.

A positive linear relationship was observed between maize yield and chloride and water chemistry in the control treatment. I observed a negative sign for the interaction with the amount of humus at the two higher compost rates of 18 and 27 t ha^{-1}. No relationship was found between the other soil chemical properties tested and maize yield in 2007.

At the lowest dose (9 t ha^{-1}), I observed a positive relationship between green pea yield and soil pH(KCl) and pH(H_2O) in the experimental area this year. There was also a positive correlation between the phosphorus content and the yield of the test crop in the 27 t ha^{-1} plot. No interaction between the parameters presented and the test crops was observed this year.

I observed a negative correlation between triticale yield and soil pH {pH(H_2O), pH(KCl)} as a result of 18 t ha^{-1} treatment in 2008. A similar relationship was observed between potassium chloride pH and triticale yield at the 9 t ha^{-1} dose.

In 2008, for maize yields, a positive relationship was observed only when comparing potassium content at a dose of 27 t ha^{-1}. Green pea yield showed a positive correlation with aqueous pH in the 9 and 18 t ha^{-1} treatments. Also, I observed a positive correlation between green pea yield and K_2O content in the 18 t ha^{-1} treatment. In the year presented (2008), I did not observe any statistical correlation between the other parameters studied.

In 2009, I could not detect any correlation between green pea yields and the parameters studied. I observed a positive linear relationship between triticale yield and soil potassium content in plots with control, 18 and 27 t ha^{-1}. Similar positive results were observed for total soil zinc content and triticale yield data in the control plots.

Maize yield was negatively affected by soil Zn and humus in untreated plots. Also, the yield of the above-mentioned test crop was negatively affected this year by the development of humus and potassium content in response to the 18 t ha^{-1} dose.

For maize yield, a dose of 9 t ha^{-1} was favourable for soil phosphorus. Further calculations did not show a linear relationship between the test crops and the parameters studied.

In 2010, I observed a positive correlation between soil P_2O_5 and zinc content and triticale yield in the 18 t ha^{-1} treatment. Similar results were obtained between Zn content and test crop yield in the control area.

In this year (2010), maize yield was negatively affected by soil pH {pH(H_2O), pH(KCl)} for all three compost rates (9, 18 and 27 t ha^{-1}). Yield of this test crop was positively affected by soil potassium content in the 18 t ha^{-1} treatment and total soil Zn in the 27 t ha^{-1} plot. Yields of a third test crop (green peas) also showed a negative interaction for both soil pH effects tested at the 18 t ha^{-1} dose and for soil phosphorus in plots containing 9 t ha^{-1} of compost mixture. No statistically verifiable correlations were found between yields and the other parameters studied.

The yield of triticale was not affected by soil pH in 2012. A negative correlation was observed between maize yield and soil pH {pH(H_2O), pH(KCl)} for the 18 t ha^{-1} treatment. I also observed a similar correlation between soil phosphorus content and yield of this test crop. The amount of copper and zinc in the soil also had a negative effect on the grain yield of maize in the compost treatment at the highest rate (27 t ha^{-1}).

A positive correlation was found between the yield of green peas and soil P_2O_5 content and soil Cu content. The former at 9 t ha^{-1} and the latter based on the results measured in the control plots. Negative effects on test crop grain yields were observed for soil potassium content and copper content in fields containing 9 t of compost mixture. No further correlation was observed between the soil pH described and the yield of the test crops this year.

In the last year of the study (2013), only positive correlations were observed between triticale yield and the soil pH properties tested. Potassium chloride and aqueous pH, phosphorus and potassium in the 9 t ha^{-1} treatment and the two macro elements in the 18 t ha^{-1} dose treated fields were also favourably affected. Even at the 27 t compost rate, K_2O content had an effect on test crop grain yield.

In the case of maize, only at the highest dose (27 t ha^{-1}) was there a positive interaction between soil zinc content and test crop yield. Grain yield was negatively affected by soil pH in the 18 and 27 t ha^{-1} treatments and also negatively affected by soil potassium content in the 18 t ha^{-1} dose on the test crop.

Soil pH had a negative effect on the grain yield of green peas in the 18 t ha^{-1} treatments. This year, soil zinc content was not beneficial to test crop yield in the control treatment.

4. CONCLUSIONS AND SUGGESTIONS

The primary objective of my thesis was to demonstrate the effect of the use of municipal sewage sludge compost for nutrient replenishment on soil chemistry and crop yields. I monitored changes in soil physical properties, elemental content and yield of test crops over seven years of the study period using a large field experiment.

The unrestricted use of the fertiliser (NYÍRKOMPOSZT) was applied to the experimental area every three years - similar to the practical application method for organic fertiliser.

Soil pH values are generally most favourable around the neutral range, taking into account a number of properties. The acidic pH of sandy soils reduces the uptake of nutrients, while mobilising a significant proportion of toxic elements. Since sewage sludge compost always contains toxic and potentially toxic elements, maintaining and, if necessary, improving soil pH is a priority. As the chemical composition of the compost product used is in the neutral range, it is in itself suitable for improving soil pH.

The positive impact of sewage sludge compost, which is extremely rich in organic matter, could be significantly enhanced in the coming years, as the price of raw materials for fertiliser production and the finished product has increased significantly, not to mention the global supply problems we are facing today, so farmers will look for cheaper and good quality, locally available, nutrient-dense fertilisers. In addition, the beneficial effects on the soil should not be forgotten.

Based on my experimental results, it can be concluded that different plant species respond differently to sewage sludge compost treatment, which should be taken into account in practical applications, both when planning crop rotation and when selecting species. Of the three test crops included in the study, triticale, grown as a leguminous crop, showed a long-term positive effect on yields from sewage sludge compost treatment. In only one year (2009) of the period presented (2007-2013), the crop did not produce more than 9 t ha^{-1} in the treatment. The results show that among the higher doses, plots with 18 t ha^{-1} in one year and 27 t ha^{-1} in the other year gave the higher seed yield. Outstanding yields were measured in the second years after repeated sprays, which farmers should take into account when planning their sowing structure. Maize has also responded positively to compost treatments at different doses in the 2008-2013 period. Changes in green pea yields in response to different compost treatments at different rates showed highly variable results over the 6 years presented, strongly influenced by weather variability.

5. NEW SCIENTIFIC RESULTS

During the preparation of my thesis, I investigated the agricultural use of compost from sewage sludge of municipal origin in a field plot experiment. I observed the effects of the unrestricted use of this fertiliser on the soil and the crop over a period of seven years.

My new scientific findings are:

- I have demonstrated that two applications of municipal sewage sludge compost at 27 t ha^{-1} on acid siliceous sandy soils increased maize test crop yield by 25% and triticale test crop yield by 27%. The most beneficial effects were observed in the second year after application. In contrast, green pea yields did not respond to regular application of sewage sludge compost.
- I have shown that long-term and regular application of sewage sludge compost designed for acidic sandy soils continuously increases soil pH. A dose of 27 t ha^{-1} raised the pH to 7.23 over 7 years, compared with a pH of 3.63 in the upper 0-30 cm of the control soil.
- I have shown that long-term and regular application of sewage sludge compost designed for acid sandy soils increased the organic matter content of the soil in the upper 0-30 cm layer. The compost application rate of 27 t ha^{-1} increased the soil organic matter content to 1.01 compared to 0.78 for the control soil over 7 years.

- My tests demonstrated that sewage sludge compost applied regularly to acid siliceous sandy soils had a positive effect on soil organic matter content in the deeper 30-60 cm soil layer. Doses of 18 and 27 t ha^{-1} increased soil humus(%) to 0.72 compared to 0.65 humus(%) in the control soil over 7 years.
- I have shown that in the set plot experiment, triticale yield and soil potassium uptake are positively related, and my results support the negative correlation between maize yield and soil pH.
- In a small plot experiment I have shown that regular application of sewage sludge compost on acid sandy soils can increase the zinc uptake in the soil.
- I found that no accumulation of copper and zinc was observed in the grain yield of the test plants in the acid sand soil experiment. During the test, the values measured in the grain yields were below the concentrations typical of plants growing on unpolluted soil.

6. APPEARED PUBLICATIONS IN THE SUBJECTS OF THE DISSERTATION

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My further publications can be found on the MTMT page at the following link:

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