SZENT ISTVÁN UNIVERSITY

DOCTORAL SCHOOL OF ENVIRONMENTAL SCIENCES

Investigation of agricultural application of anaerobic digestate

MIKLÓS GULYÁS

Gödöllő

2017

Ph.D. School

Name:	Szent István University Doctoral School of Environmental Sciences
Discipline:	Environmental Sciences
Head of school:	Csákiné Dr. Michéli Erika professor SZIE, Faculty of Agricultural and Environmental Sciences, Institute of Environmental Sciences
Scientific supervisor:	Dr. Füleky György professor emeritus SZIE, Faculty of Agricultural and Environmental Sciences, Institute of Environmental Sciences

________________________ ________________________

Approval of Head of School Approval of Scientific Supervisor

Introduction and objectives

The agricultural production is not only an industrial raw material source, agricultural works as a receiver of many industrial byproducts with different qualities, which are used in crop production as an alternative nutrient source (Mekki et al., 2013, Piotrowska et al., 2006; Van Zwieten et al., 2010; Kádár et al., 2009; Kovács et al., 2005). Many other organic materials are applied currently, such as different manures which had been also used (Ndayegamiye és Cote, 1989; Balla, 1963). The treatment and transformation of these industrial and municipal byproducts make the new researches and monitoring necessary. Some materials which are never used, can be alternative sources of soil fertility preservation and conservation

In 19th century wide range of biogas plants are appeared and started to apply the anaerobic digestate on field. It was necessary to analyze the direct and indirect effects of digestate application, but these research works went on few years later. The effects depend on the substrate quality, which is based on the type and the mixture of the raw material, and the circumstances of the used technology. The outcome also depends on the amount of applied digestate, soil type and test plants additionally. Harmonization and adaptation of archive and new data, and new researches are needed to understand the interactions among various digestates, soil, crop, and climatic condition (Nkoa, 2014).

From the 2000's number of Hungarian research team also started to study the effect of applied digestate but these researches are completed soon in the absence of support (Makádi et al., 2007c, Somosné and Szolnoky, 2009, Vágó et al., 2008). Despite the fact that the Hungarian Academy of Agricultural Sciences has declared this area as a priority research topic, the Hungarian literature is very poor.

The aim of my work was to investigate the effect of different doses of digestate and the incubation time on the physical and chemical properties of the soil, as well as the weight and germination of ryegrass (*Lolium perenne*). The purpose of the study was to answer the following questions:

- The time effect from the mixing of digestate application on the soil mineral N form changes and the germination dynamics of ryegrass.
- Anaerobic digestate effect on various soil properties. Digestate effect on ryegrass growth and N uptake in laboratory pot experiment.
- Monitoring the effect of the applied digestate on the transformation of mineral nitrogen forms, the germination dynamics of ryegrass focused on the ammonium toxicity.
- Bonechar, biochar and the digestate effect on the soil physical and chemical properties.
- Bonechar, biochar and the digestate effect on the ryegrass yield, nutrient content and uptake.

Materials and methods

The effect of anaerobic digestate (contains sewage sludge) was measured on various soil textures under laboratory conditions in my dissertacion. Tests are extended to the soil physical and chemical properties and the nutrient uptake of the plants. Further experiments are set to investigate other additives effect like bonechar and biochar.

Soil samples are originated from the top plowed layer (Ap) (0-30 cm). Samples were stored under dry, cool (+5°C) place till usage, in the preparation method we cleaned the soil from the plant residues, grounded and homogenized and sieved the air dried soil through 2 mm sieve (22-24°C). According to the humus content: the nitrogen supply was good in humic sandy soil, the AL-P_2O_5 content was good, AL-K_2O content was in the medium category by MÉM-NAK. The plasticity index of chernozem soil was (K_A) 51, humus content was 3,2 %, AL-P_2O_5 content was 385 mg kg^{-1}, AL-K_2O content was 461 mg kg^{-1}. According to the MÉM-NAK in means the nitrogen supply is good, the AL-P_2O_5 and AL-K_2O content also is very good.

Parameters	**Concentrations**	**In dry matter**	**Limit value***
Dry matter %	7,60	100%	
Loss of ignition %		55,38%	
pH (H_2O)	8,07		
Kjeldahl-N mg kg^{-1}	5320	70044	
KCl NH_4-N mg kg^{-1}	2557	33665	
KCl NO_3-N mg kg^{-1}	33,1	435	
KCl NH_4+NO_3-N mg kg^{-1}	2590	34099	
Total-P mg kg^{-1}	2531	33326	
Total-K mg kg^{-1}	13,4	177	
HNO_3 Ca mg kg^{-1}	883	11630	
HNO_3 Mg mg kg^{-1}	421	5538	
HNO_3 Cu mg kg^{-1}	1,93	25,5	1000 mg kg^{-1}
HNO_3 Zn mg kg^{-1}	64,7	851	2500 mg kg^{-1}
HNO_3 Fe mg kg^{-1}	941	12386	-
HNO_3 Mn mg kg^{-1}	24,4	321	-
HNO_3 Pb mg kg^{-1}	4,59	60,4	750 mg kg^{-1}
HNO_3 Cd mg kg^{-1}	0,39	5,17	10 mg kg^{-1}
HNO_3 Ni mg kg^{-1}	2,96	39,0	200 mg kg^{-1}

*According to 50/2001. (IV. 3.) Goverment regulation

Table 1.: Chemical parameters of anaerobic digestate, 2010

The results show that the nutrient content of the digestate is in soluble form mainly, plants can take up easily this form from the soil. The digestate was homogenized and the original form was applied on the soil in each case. Sowing happened before the mixing directly.

The used plant originated biochar and the bonechar (Table 2.) made in the Terra Humana Ltd. plant in the az EU FP7 REFERTIL 289785 project. The entire process is protected by patent, so the presented information are originated from the project documentation. Both chars made by pyrolysis technology, this technology convert the organic materials at high temperature (450-650°C) in reductive environment and under negative pressure, one of the endproduct is the biochar.

Parameters	**BC**	**ABC**	**Parameters**	**BC**	**ABC**

a, Particle size, %			j, Element content,		
>6,3 mm	<0,1	<0,1	mg kg^{-1}	30	300
3,15-6,3 mm	8,2	72,0	Calcium (Ca)	200	000
2-3,15 mm	22,6	13,2	Chromium (Cr)	4	4
1,6-2 mm	6,2	1,9	Cupper (Cu)	9	5
1-1,6 mm	34,4	4,2	Iron (Fe)	2 280	63
0,63-1 mm	6,4	0,8	Potassium (K)	4 450	2 000
0,1-0,63 mm	20,4	7,1	Magnesium (Mg)	1 200	6 000
<0,1 mm	1,8	0,8	Manganese (Mn)	1 140	1
b, Bulk density, g cm^{-3}	0,36	0,31	Sodium (Na)	170	7 000
c, Dry matter, %	93,87	99,95	Phosphorus (P)	780	133
d, Ash, %	11,61	100	Zinc (Zn)	41	000
e, Total-C, %	79,8	9,9	Nitrite (KCl-NO_2)	0,4	152
f, Total-N, %	0,7	1,8	Nitrate (KCl-NO_3)	<10	0,6
g, C/N ratio	99,4	5,1	Potassium (AL-K)	1 450	<10
h, pH,	8,32	7,58	Phosphorus (AL-P)	214	1 500
i, CEC, cmol kg^{-1}			k, Total PAH, mg kg^{-1}	4,82	24 600
	14,7	n.a.			0,37
			l, Total PCB	-	
					-

Table 2.: Laboratory analysis result of biochar and bonechar, 2014 (Wessling Hungary Kft, 2013; EU FP7 REFERTIL 289785, 2013; Gulyás et.al., 2014)
*BC: plant origin biochar, ABC: bonechar

Biochar applied as a soil conditioner mainly thanks to the high carbon content and micro and mezo size of pores (1-50 nm), while the bonechar has low carbon content and very high calcium and phosphorus content, that is the reason why it is suitable to nutrient supply. Thanks to the technology it has macroporous texture (50-63000 nm), size of the pores have significant effect also (Someus, 2016).

Biotest experiments in 2010

To investigate the effcet of digestate 1 gram of ryegrass (*Lolium perenne*) was sowed to a round plastic container (44x155mm), the volume was 500 cm^3. The digestate application levels depended on the EU Nitrate Directive maximum level, 170 kg N ha^{-1}. At the end of the test period the ryegrass was cut off on the 15 days. From the samples from Szárítópuszta (humic sand) the following treatments was set up in three replications:

- Control: 200g soil
- 1.treatment: 200g soil + 42,5 kg ha^{-1} N digestate
- 2.treatment: 200g soil + 85 kg ha^{-1} N digestate
- 3.treatment: 200g soil + 127,5 kg ha^{-1} N digestate
- 4.treatment: 200g soil + 170 kg ha^{-1} N digestate

Biotest experiments in 2011

The preparation and mixing process was the same like in 2010. From the samples from Szárítópuszta (humic sand) the following treatments was set up in three replications:

- Control: 200g soil
- 1.treatment: 200g soil + 25 kg ha^{-1} N digestate
- 2.treatment: 200g soil + 50 kg ha^{-1} N digestate
- 3.treatment: 200g soil + 75 kg ha^{-1} N digestate

- 4.treatment: 200g soil + 100 kg ha^{-1} N digestate

Biotest Experiments in 2012

From the samples from Szárítópuszta (humic sand) the following treatments was set up in three replications, in 2012:

- Control: 200g soil
- 1.treatment: 200g soil + 25 kg ha^{-1} N digestate
- 2.treatment: 200g soil + 50 kg ha^{-1} N digestate
- 3.treatment: 200g soil + 75 kg ha^{-1} N digestate
- 4.treatment: 200g soil + 100 kg ha^{-1} N digestate

In the year of 2012 new samples were collected from the experimental site of SZIU Józsefmajor, so I could made experiments on better soil physical and nutrition supply condition. The aim of the experiment was to monitor the transformation of nitrogen forms. From the samples from Józsefmajor (chernozem) the following treatments were set up in 10 replications:

- Control: 200g soil
- 1.treatment: 200g soil + 80 kg ha^{-1} N digestate
- 2.treatment: 200g soil + 120 kg ha^{-1} N digestate
- 3.treatment: 200g soil + 170 kg ha^{-1} N digestate

Biotest experimenrts 2013

Humic sand soil was used in this expeiment. Solid pyrolysis byproduct, which are originated from the EU FP7 REFERTIL 289785 project, was added to the soil. These solid chars totally made from organic wastes. From the samples from Szárítópuszta (humic sand) two factor split-plot experiment was set up in three replications:

A. Treatments:

- Control: 1000g soil
- 1.treatment: 990g soil + 10g biochar
- 2.treatment: 975g soil + 25g biochar
- 3.treatment: 950g soil + 50g biochar
- 4.treatment: 900g soil + 100g biochar
- 5.treatment: 990g soil + 10g bonechar
- 6.treatment: 975g soil + 25g bonechar
- 7.treatment: 950g soil + 50g bonechar
- 8.treatment: 900g soil + 100g bonechar

B. Treatments:

- Control: 1000g soil + 170 kg ha^{-1} N digestate
- 1.treatment: 990g soil + 10g biochar + 170 kg ha^{-1} N digestate
- 2.treatment: 975g soil + 25g biochar + 170 kg ha^{-1} N digestate
- 3.treatment: 950g soil + 50g biochar + 170 kg ha^{-1} N digestate
- 4.treatment: 900g soil + 100g biochar + 170 kg ha^{-1} N digestate
- 5.treatment: 990g soil + 10g bonechar + 170 kg ha^{-1} N digestate
- 6.treatment: 975g soil + 25g bonechar + 170 kg ha^{-1} N digestate

– 7.treatment: 950g soil + 50g bonechar + 170 kg ha^{-1} N digestate
– 8.treatment: 900g soil + 100g bonechar + 170 kg ha^{-1} N digestate

The experiment period was 30 days, nine treatments in three replications was carried out. To the preparation of small plastic containers approximately 1000 g prepared soil was used and this was mixed with the given amount - 1%, 2,5%, 5%, 10% volume percent – of biochar and bonechar. From these mixtures 200 grams were measured into a 500 cm^3 container in three replications. Two grams of ryegrass (*Lolium perenne*) was sowed to a container. The same experiment was repeated, except that digestate was applied instead of distilled water for the mixture. The digestate application levels depended on the EU Nitrate Directive maximum level, 170 kg N ha^{-1}.

Results and discussion

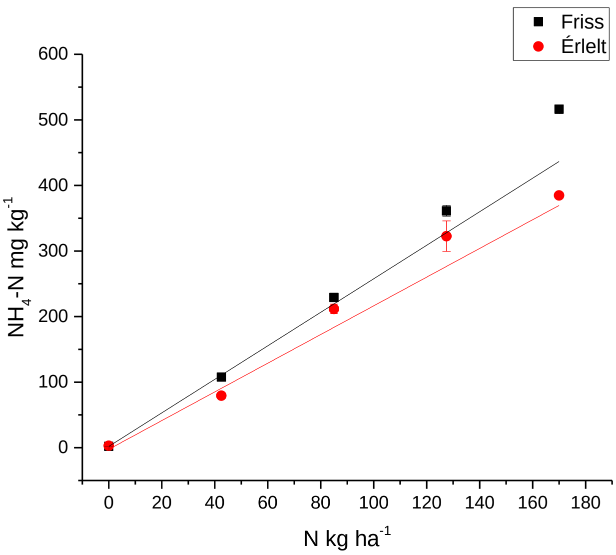

Figure 1. The effect of nitrogen from digestate application on NH_4-N content on humic sand soil, 2010

* 0- control, 42,5- 42,5 kg ha^{-1} N digestate, 85- 85 kg ha^{-1} N digestate, 127,5- 127,5 kg ha^{-1} N digestate, 170- 170 kg ha^{-1} N digestate

The increasing amount of organic N of applied digestate caused proportionately increasing in the ammonium ion concentration of soil compared to the control. Results showed a significant decreasing of NH_4-N concentration after the 14 days aging period, that caused the nitrification process (Figure 1.).

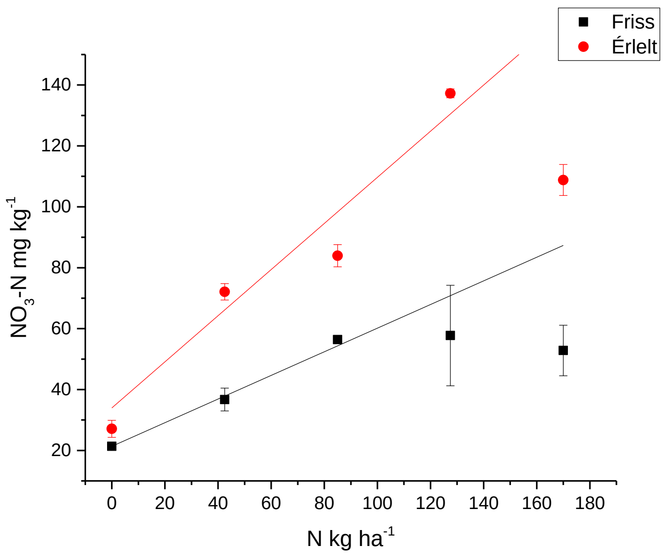

Figure 2. The effect of nitrogen from digestate application and the aging on NO_3-N content on humic sand soil, 2010

* 0- control, 42,5- 42,5 kg ha^{-1} N digestate, 85- 85 kg ha^{-1} N digestate, 127,5- 127,5 kg ha^{-1} N digestate, 170- 170 kg ha^{-1} N digestate

The given amount of NO_3-N was almost the same without aging, but thanks to aging the values were increased. Significant inceasing was observed at the treatment of 127,5 kg ha^{-1} N (Figure 2.).

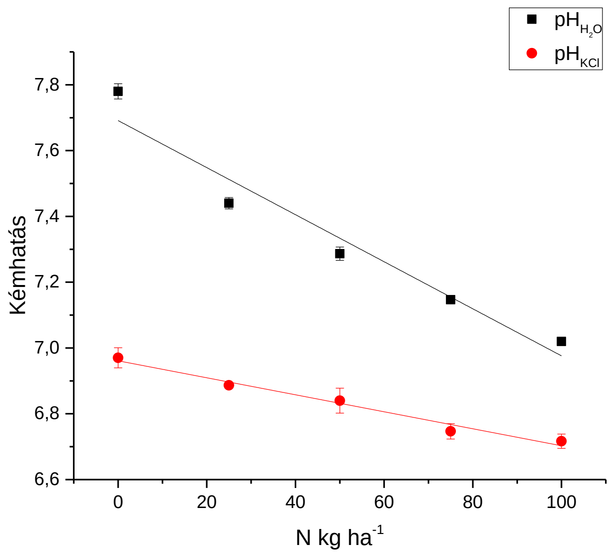

Figure 3. The effect of anaerobic digestate on pH of humic sand soil, 2011

* 0- control, 25- 25 kg ha^{-1} N digestate, 50- 50 kg ha^{-1} N digestate, 75- 75 kg ha^{-1} N digestate, 100- 100 kg ha^{-1} N digestate

The effect of digestate on soil pH are shown in Figure 3. The evaluation showed that the incresing amount of digestate decrease the pH of soil, both pH (H_2O) (r^2= 0,9504), pH (KCl) (r^2= 0,97941) were decreased.

Although the digestate was alkaline (pH > 8), the high ammonium content went through various microbiological transformation processes, that caused the decrease of the pH. The amount of variuos ammonium salts were high in the digestate, caused by the anaerobic conditions. During the nitrification process H^+-ions are formed in the soil.

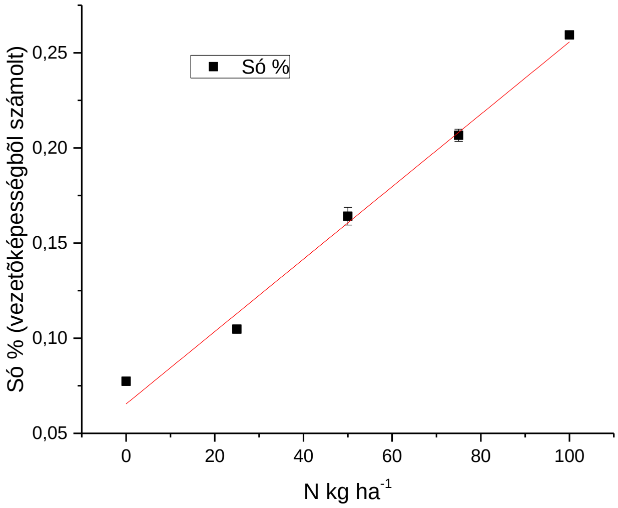

Figure 4. The effect of digestate on soil total salt content of humic sand soil, 2011
* 0- control, 25- 25 kg ha^{-1} N digestate, 50- 50 kg ha^{-1} N digestate, 75- 75 kg ha^{-1} N digestate, 100- 100 kg ha^{-1} N digestate

The digestate increased the total salt content from 0,07% to 0,25% (Figure 4.). Treatments had significant effect (r^2 = 0,98712). According to the Stefanovits et. al., 1999 this soil is not salty, but the digestate containes high amount of mineral salt. The high salt content depend on the raw materials. Those plants where the raw material contains manure the digestate has to be higher salt content due to the salt licking stone. We could not find clear sign of salinity but the salt content increased. In the long term, systematic application of digestate have to be monitore to avoid the salt accumulation.

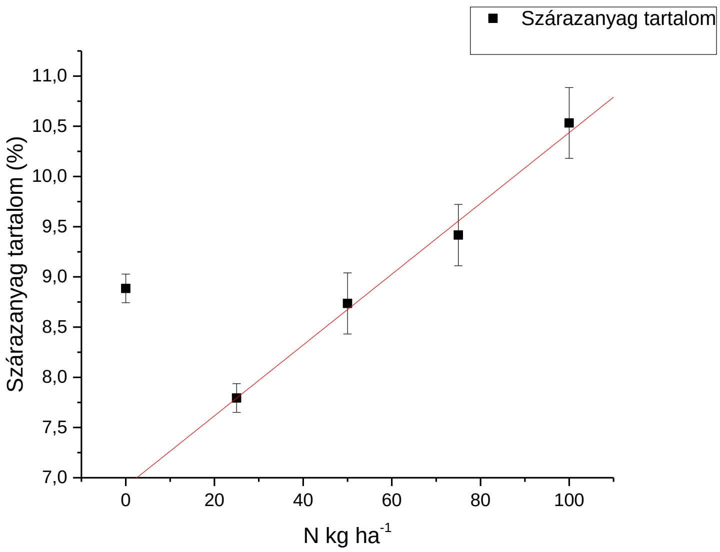

Figure 5. The digestate effect of the ryegrass dry matter content on humic sand soil, 2011
* 0- control, 25- 25 kg ha^{-1} N digestate, 50- 50 kg ha^{-1} N digestate, 75- 75 kg ha^{-1} N digestate, 100- 100 kg ha^{-1} N digestate

The effect of digestate on the dry matter changes of ryegrass are shown Figure 5. The standard deviation is not significant. The dry matter content of ryegrass was higher in the control treatment than in the first two N level, this result also found in literature. This effect called as dillution effect. According to Mischerlich's law the nutrient which is in minimum level – at the presest situation the nitrogen – lower doses of it have the maximum specific effect on the yield. The fresh yield increses more quickly than the dry yield. That is the reason of decreasing of the dry matter compared to the control. The higher nitrogen doses caused a little increasing in yield but the N content of ryegrass increased so the dry matter content, too.

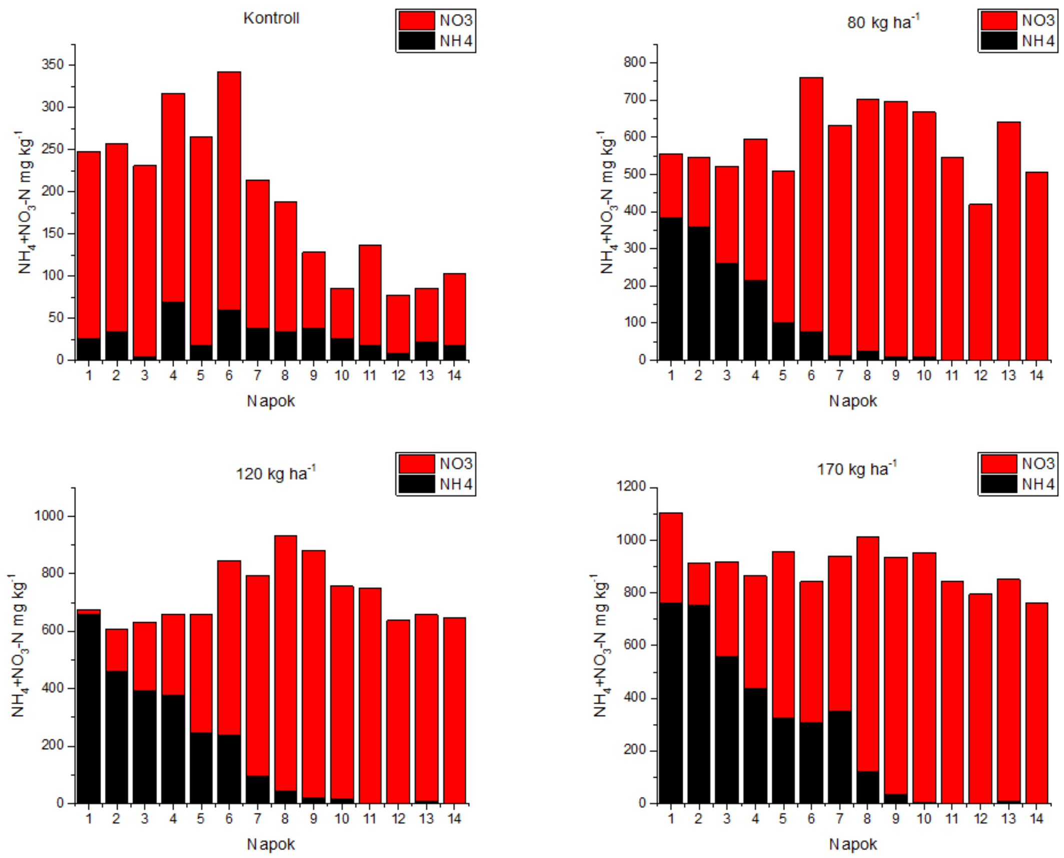

Figure 6. The effect of the digestate and the time after mixing on the NH_4-N and NO_3-N content changes, 2012

* 0- control, 80- 80 kg ha^{-1} N digestate, 120- 120 kg ha^{-1} N digestate, 170- 170 kg ha^{-1} N digestate

The ammonium ion concentration was negligible in control treatment, and did not show significant changes in time on chernozem soil pot experiment. The samples treated with digestate showed sharp decreasing in the first days after mixing. The 80 kg treatment on the 7-8th days, the 120kg treatment on the 9th days, and the 170kg treatment on the 10th days reached the level which was measured in control (Figure 6).

The nitrate concentration showed quite different trend compared to the other treatments. While the nitrate ion content of control stagnant to the 7 th days, but from this time taperd off. The other treatments showed increase until the 8-10th days then continous decrease was monitored. This trend should caused by the increasing nitrogen uptake of ryegrass in both control and digestate treatments.

To summarize the changes of both nitrogen form, we can say that the digestate application caused high ammonium ion concentration which was suitable for the expected value. The smaller part of this ammonia gas should release into the air, and absorbed on the surface of soil colloids, the bigger part of it transformed into nitrate due to the nitrifying bacteria. This process ended on the 6-7th days, from this time only the nitrate ion concentration was measurable. The nitrate ion decreasing from the 11th days caused by the N uptake of germinated plants.

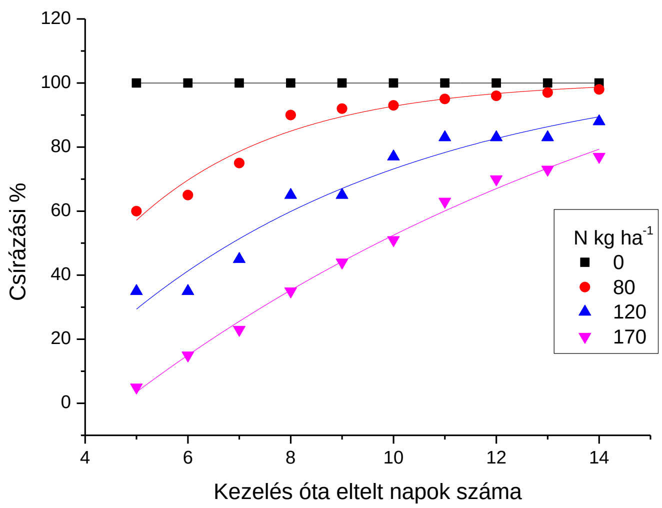

Figure 7. Germination ratio according to the days, 2012

* 0- control, 80- 80 kg ha^{-1} N digestate, 120- 120 kg ha^{-1} N digestate, 170- 170 kg ha^{-1} N digestate

Figure 7. showest that the control treatment – treated with distilled water – resulted the highest germination rate during the test period. The next was the 80 kg treatment (r^2=0,96102) which contains the lowest amount of digestate. This treatment was very close to the control from the 8th days. The 120 kg ha^{-1} N treatment caused quite slow germination (r^2=0,95694). We can see that the germination ratio approximately will be on the same level than the control only at the end of the second week. The 170 kg treatment showed the slowest germination rate. It is clearly visbile that is the steepest liner on the graph (r^2=0,99502). This means that the germination was slow but after few days the germination rapidly grew. The fitted lines refer to very close connections, depends on the r^2 values. Furthermore it is observed that the 170 kg treatment caused the lowest germination rate in the beginning, but later it changed and the germination rate was the highest. The microbiological transformation of ammonium decreased the anti-sprouting effect.

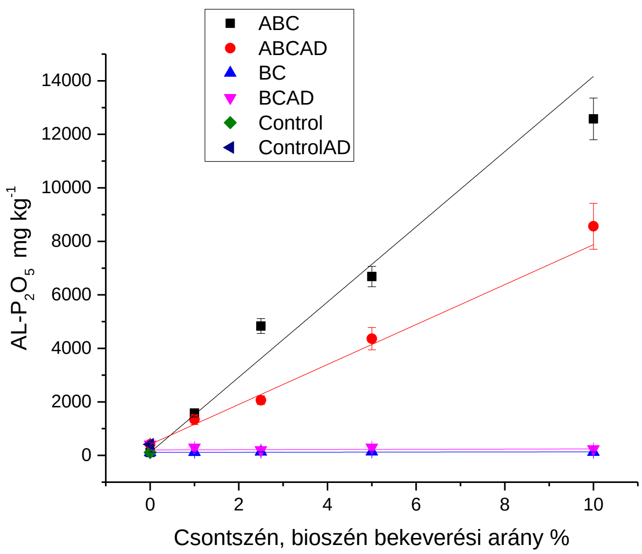

Figure 8. The effect of bonechar, biochar and digestate on the soil AL-P_2O_5 - changes, 2013

* Control- control, ControlAD- digestate control, ABC- bonechar, ABCAD- bonechar +digestate, BC- biochar, BCAD- biochar+digestate

The doses of bonechar (ABC) significantly increased the easy soluble phosphorous content of soil (r^2=0,97393) (Figure 8). The results clearly shows the increasing amount of bonechar. The highest, 10% doses of bonechar caused 100 times higher AL-P_2O_5 content cmpared to the control. The bonechar and the added digestate treatment resulted one third decreasing of AL-soluble phosphorous content, but the the bonechar effcet is undisputed (r^2=0,98694). Supposedly to the common use hardly soluble inorganic (calcium-phosphate) and organic (phytates) forms evolved, and the alkaline pH create good environment for it.

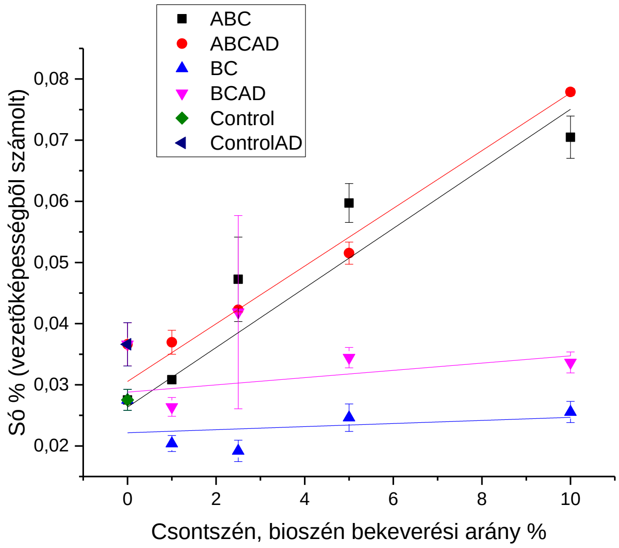

Figure 9. The effect of bonechar, biochar and digestate on the soil total salt content, 2013

* Control- control, ControlAD- digestate control, ABC- bonechar, ABCAD- bonechar +digestate, BC- biochar, BCAD- biochar+digestate

The biochar (BC) treatments did not show statistical effect on the salt content of soil (r^2=0,07831) during the experiment, but some decrease was observed due to the treatments. Biochar and digestate treatments did not show significant effcet either (r^2=0,33167), however the digestate application increased the salt content of soil. The digestate contributed to increase the salt content itself, as it was showed earlier, but it was not significant (Figure 9).

The given amount of bonechar (ABC) gradually increased the salt content (r^2=0,9428), due to the higher mineral content of bonechar mainly. The salt content was around 0,07% in the highest bonechar (10%) treatment. The additional digestate increased more intensively the water soluble salt content (r^2=0,99801), but the bonechar application caused the extrem increasing clearly.

This significant increase of salt content revealed that long term experiment are necessary because in case of regular use it can cause harmful level of salt accumulation, secondary salinisation and plant toxicity. According to the literature the 5% or higher doses cause such accumulation (Revell, 2011).

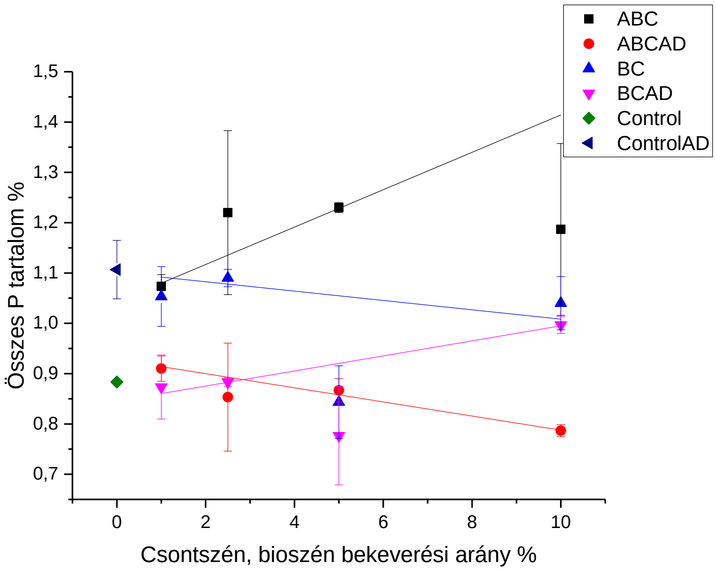

Figure 10. The effect of bonechar, biochar and digestate on the phosphorous content of ryegrass, 2013

* Control- control, ControlAD- digestate control, ABC- bonechar, ABCAD- bonechar +digestate, BC- biochar, BCAD- biochar+digestate

The extremely high phosphorous content of bonechar contributed to the plants utilize more phosphorous from the soil solution (r^2=0,94366). The additional digestate caused that the phosphorous content of plants significantly decreased (r^2=0,98734), the values were the same like in the control treatment.

The biochar treatments increased the phosphorous content of ryegrass, but the different doses did not show differences between the phosphorous content of the plants (r^2=0,15001), as the treatments did not effect on the soil phosphorous content. The additional digestate caused higher phosphorous content it was influenced by the biochar doses (r^2=0,94206). However this phosphorous content was under the control value (Figure 10).

Bonechar had significant effect on the phosphorous content of ryegrass, while the biochar had slightly effect but the doses did not show effect. Digestate application caused decreasing phosphorous content of the plant each case. The combination of alkaline environment, the high calcium content and the antagonistic effect can cause this effect.

According to the literature the phosphorous content of the ryegrass depend on the age, it changes 0,2-0,4%. The values below and above can cause yield loss (Reuter and Robinson, 1997).

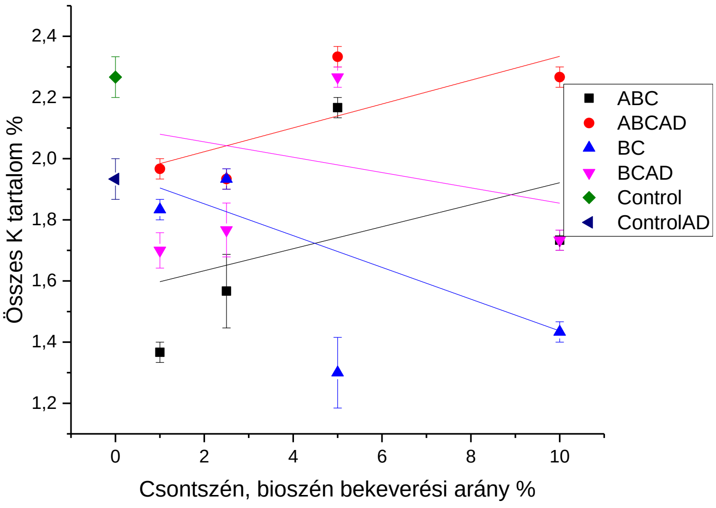

Figure 11. The effect of bonechar, biochar and digestate on the potassium content of ryegrass, 2013

* Control- control, ControlAD- digestate control, ABC- bonechar, ABCAD- bonechar +digestate, BC- biochar, BCAD- biochar+digestate

Biochar is an excellent source of potassium, which enriched the soil AL soluble potassium fraction but the plant reaction was different. Significantly decreased the potassium content of plants compared to the control.

Bonechar treatments also were below the control (Figure 11).

The effect of the combination of bonechar and digestate proved clearly. The higher doses helped to increase the potassium content in plants. The critical potassium value in ryegrass is 0,2%. In this case my result higher than this value so this was no problem.

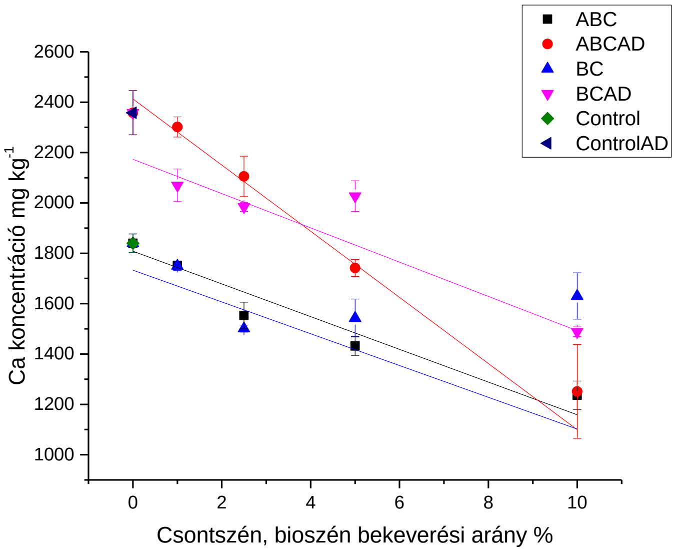

Figure 12. The effect of bonechar, biochar and digestate on ryegrass calcium content, 2013

* Control- control, ControlAD- digestate control, ABC- bonechar, ABCAD- bonechar +digestate, BC- biochar, BCAD- biochar+digestate

The calcium concentration of the plants was below the control in all case and it significantly decreased (ABC - r^2 =0,94619; ABCAD - r^2 =0,98959; BC - r^2

=0,41571; BCAD - r^2 =0,96341). The additional digestate caused better calcium availability, thanks to the easy soluble forms (Figure 12).

Despite the significant calcium content of biochars they does not contribute to the calcium availability and it can be adsorb. The plant uptake is a good example compared to the control.

According to the literature the 0,2% (2000 mg kg^{-1}) calcium concentration means deficit.

Due to the high potassium content of bichar doses it caused Ca deficit in the test plants because of the known K-Ca-Mg antagonism (Kádár, 1997). This calcium deficit should cause yield reduction too, because the Ca content of the plant decreasing further during the vegetation period (Lásztity, 1986).

New scientific results

1. I have found that the germination dynamics of the ryegrass was inhibited proportionately with the digestate amount on humic sand soil in laboratory experiment.
2. The additional digestate increased the plants nitrogen uptake durind the 14 days test period. The better nitrogen supply caused higher yield and better composition.
3. I demonstrated, that the digestate anti-sprouting effect take till the total transformation of toxic NH_4-N content to nitrate. This time was on the 7-8th days in my pot experiment on ryegrass.
4. The bonechar caused increasing salt content on soil which is unfavourable. The digestate increased slightly the salinity. The shoot mass of ryegrass increased until 2,5% of bonechar and biochar. The calcium and magnesium concentration decreased in all cases.
5. I have found that the biochar had positive effect on soil platicity index. The bonechar and the bonechar digestate mixture increased the pH of soil. The AL-soluble phosphorous content increased the bonechar multiple time while the biochar caused the same effect on the AL- soluble potassium which was raised by the applied digestate. Doses of biochar significantly increased the carbon content of soil.

Conclusions and suggestions

Researches started in the recent years in Europe to investigate the role of digestate in soil-plant system. This material is extremly versatile so we have to know the expected effects before the application. These effects work under factual case and environment so we can get general conclusions to application from systematic and long term experiments only.

To understand the sub-processes more detailed and coordinated research works are needed. The results and the analysis of results show that the wide range of microbiological measurements should we use because it has significant effect. There are an outstanding role of the chemical and physical processes in the background.

The long term experiments are totally missing in Hungary. It is our common goal and interest to establish and support these to gain more information. I have a 4 year-old open field experiment which is going on to supporting the farmers.

It would be necessary to set up experiments with different sowing times after the mixing to match the digestate in plant nutrition technology. The nitrification process was quite faster in my experiments than we found in the literarture. Under field condition this time will be shorter, this information is essential to determine the exact time of sowing.

The used small pots are not suitable to grow the ryegrass until the necessary phenological phase which is suiatble for the diagnostical measurements. However, this method and the ryegrass are good for rapid toxicity tests. It is more safe to grow the plants in larger pots because the nutrient supply of the plants will be better and measurable.

Related publications

1. Peer-reviewed research articles

1.1. With impact factor (according to WEB OF SCIENCE), in English:
1.1.1. Hungarian publischer:
1.1.2. International publischer:

B Glina , A Bogacz , M Gulyás , B Zawieja , P Gajewski , Z Kaczmarek
The effect of long-term forestry drainage on the current state of peatland soils: A case study from the Central Sudetes, SW Poland
MIRES AND PEAT 18: pp. 1-11. (2016) **(18 pont) (IF=1,095)**

1.2. In English, without IF
1.2.1. Hungarian publisher

Miklós Gulyás , András Béres , László Tolner , László Aleksza , Imre Cinkota
Effects of hot water extracts of a composted green waste and sewage sludge on plant germination in model experiment
HUNGARIAN AGRICULTURAL RESEARCH 24:(3) pp. 12-15. (2015) **(7pont)**

Gulyás Miklós, Béres András, Dér Sándor, Aleksza László
The investigation of respiration after mechanical biological treatment of municipal solid waste
HUNGARIAN AGRICULTURAL RESEARCH 2014:(2) pp. 38-42. (2014) **(7pont)**

Gulyás M, Tomócsik A, Orosz V, Makádi M, Füleky Gy
Risk of agricultural use of sewage sludge compost and anaerobic digestate
ACTA PHYTOPATHOLOGICA ET ENTOMOLOGICA HUNGARICA 47:(2) pp. 213-221. (2012) **(7pont)**

Független idéző: 1 Összesen: 1

Komnitsas Kostas et al	ENVIRONMENTAL FORENSICS 15: 312-328 (2014)

(1pont)

1.2.2. International publisher

M Gulyás, M. Fuchs, I.Kocsis, Gy. Füleky
Effect of the soil treated with biochar on the rye-grass in laboratory experiment
ACTA UNIVERSITATIS SAPIENTIAE AGRICULTURE AND ENVIRONMENT 2014:(6) pp. 24-32. (2014) **(7pont)**

1.3. In Hungarian, without IF

Harta István , Gulyás Miklós , Füleky György
Műtrágyázás tartamhatásának vizsgálata akácosban
AGROKÉMIA ÉS TALAJTAN 65:(1) pp. 31-45. (2016) **(5pont)**

Miklós Gulyás, Márta Fuchs, Gabriella Rétháti, Annamária Holes, Zsolt Varga, István Kocsis, György Füleky
Szilárd pirolízis melléktermékekkel kezelt talaj vizsgálata tenyészedényes modellkísérletben
AGROKÉMIA ÉS TALAJTAN 63:(2) pp. 341-352. (2014) **(5pont)**

2. Professional full text article,
2.1. Professional full text article

Gulyás M, Szegi T, Makádi M, Füleky Gy
Biogázüzemi erjesztési maradékkal végzett kísérletek a mezőgazdasági felhasználás tükrében
BIOHULLADÉK 7:(1) pp. 17-21. (2013) **(2pont)**

Gulyás M, Füleky Gy
Biogázüzemű fermentlé mezőgazdasági felhasználásának vizsgálata
BIOHULLADÉK 5:(2-3) pp. 26-29. (2010) **(2pont)**

4. Conference proceedings with ISBN, ISSN or other certification
4.1. Full text article in Foreign language, peer-reviewed

Tolner L., Ziegler I., Füleky Gy., Gulyás M., Rétháti G. (2016): Stimulant and toxic effect of biomass ash dosage in pot experiment. XV. Alps-Adria Scientific Workshop Mali Losinj, Croatia (2016.04.25-30.), Növénytermelés / Crop production 65 Suppl. 43-46. **(5pont)**

Yadav D.V., Gulyás M., Fekete Gy., Béres A., Czinkota I. (2016): Effect of digestate on growth and health of soil plant system. XV. Alps-Adria Scientific Workshop Mali Losinj, Croatia (2016.04.25-30.), Növénytermelés / Crop production 65 Suppl. 111-114. **(5pont)**

Gulyás Miklós, Béres András, Tolner László, Alexa László, Czinkota Imre
Effects of hot water extracts of a composted green waste and sewage sludge on plant germination in model experiment
XIV. Alps-Adria Scientific Workshop. Neum, Bosznia-Hercegovina: 2015.05.11 - 2015.05.16.
NÖVÉNYTERMELÉS 64:(Suppl.) pp. 237-240. (2015) **(5pont)**

Gulyás Miklós, Varga Ibolya, Varga Zsolt, Fuchs Márta, Füleky György
Effects of different biochar and biogas digestate applications on soil and plant chemical properties in laboratory model experiments
NÖVÉNYTERMELÉS 63:(Suppl) pp. 197-200. (2014) **(5pont)**

Makádi M, Tomócsik A, Orosz V, Gulyás M, Lengyel J
Influencing the germination of different crops by liquid biogas digestate
In: A Tremier, C Druilhe, P- Dabert, M Maudet, J Barth S Siebert, H W Bidlingmaier (szerk.)
ORBIT 2012 Global assessment for organic resources and waste management. Konferencia helye, ideje: Rennes, Franciaország, 2012.06.12-2012.06.14.pp. 11-18. **(5pont)**

Gulyás Miklós, Füleky György
Agricultural application of biogas digestate
NÖVÉNYTERMELÉS 60:(Suppl) pp. 407-410. (2011) **(5pont)**

4.2. Full text article in Hungarian, peer-reviewed

Gulyás M, Fuchs M, Futó Z, Holes A, Füleky Gy
Bioszenek hatása homokos és agyagos szövetű talaj kémiai tulajdonságaira
In: Futó Zoltán (szerk.)
A hulladékgazdálkodás legújabb fejlesztési lehetőségei. 126 p. Konferencia helye, ideje: Szarvas, Magyarország, 2015.01.29 Szarvas: SZIE Gazdasági, Agrár- és Egészségtudományi Kar, 2015. pp. 53-62. (ISBN:978-963-269-464-1) **(3pont)**

Tolner L, Kocsis I, Czinkota I, Tolner I T, Gulyás M, Füleky Gy
A talajba kevert szilárd pirolízis termékek hatása a talajminták NIR reflektanciájára
In: Hernádi H, Sisák I , Szabóné Kele G (szerk.)
A talajok térbeli változatossága - elméleti és gyakorlati vonatkozások: Talajtani Vándorgyűlés, Keszthely. Konferencia helye, ideje: Keszthely, Magyarország, 2014.09.04 -2014.09.06. Keszthely: Talajvédelmi Alapítvány; Magyar Talajtani Társaság; Pannon Egyetem, Georgikon Kar, Növénytermesztéstani és Talajtani Tanszék, 2015. pp. 363-372. (ISBN:978-963-9639-80-5) **(3pont)**

Gulyás M, Fuchs M, Varga I, Kocsis I, Füleky Gy
Bioszénnel kezelt talajminták hatása angolperje tesztnövényre laboratóriumi modellkísérletben
In: Zsigmond Andrea Rebeka, Szigyártó Irma Lídia, Szikszai Attila (szerk.)
10. Kárpát-medencei Környezettudományi Konferencia. 320 p.
Konferencia helye, ideje: Kolozsvár, Románia, 2014.03.27-2014.03.29. Kolozsvár: Ábel Kiadó, pp. 28-32. **(3pont)**

Gulyás Miklós, Szegi Tamás, Füleky György
biogázüzemi erjesztési maradék mezőgazdasági felhasználásának vizsgálata
In: Dobos Endre, Bertóti Réka Diana, Szabóné Kele Gabriella (szerk.)
Talajtan a mezőgazdaság, a vidékfejlesztés és a környezetgazdálkodás szolgálatában: Talajtani Vándorgyűlés. Konferencia helye, ideje: Miskolc, Magyarország, 2012.08.23-2012.08.25. Budapest: Talajvédelmi Alapítvány; Magyar Talajtani Társaság, 2013. pp. 209-217. (ISBN:978-963-08-6322-3) **(3pont)**

Gulyás Miklós, Füleky György
Biogázüzemi erjesztési maradék hatása a nitrifikációs folyamatokra
In: Sándor Zsolt, Szabó András (szerk.)
Újabb kutatási eredmények a növénytudományokban. Konferencia helye, ideje: Debrecen, Magyarország, 2013.04.05pp. 17-22. **(3pont)**

Gulyás Miklós, Füleky György
Farsang Andrea, Ladányi Zsuzsanna (szerk.)
Biogázüzemi fermentlé mezőgazdasági felhasználásának vizsgálata
In: Farsang A, Ladányi Zs (szerk.)
Talajaink a változó természeti és társadalmi hatások között: Talajvédelem különszám, Talajtani vándorgyűlés 2010. 441 p.
Konferencia helye, ideje: Szeged, Magyarország, 2010.09.03-2010.09.04. Budapest;

Gödöllő: Talajvédelmi Alapítvány; Magyar Talajtani Társaság, 2011. pp. 211-219. (ISBN:978-963-306-089-6) **(3pont)**

Gulyás Miklós
Biogázüzemi fermentlé mezőgazdasági felhasználásának vizsgálata
In: Gergely Sándor (szerk.)
Zöldenergia, földhő és napenergia hasznosítása a hőtermelésben. Konferencia helye, ideje: Gyöngyös, Magyarország, 2010.05.20pp. 76-80. **(3pont)**

5. Conference proceeding without certification
5.1. Full text article in Foreign language
5.2. Full text article in Hungarian
5.3. One page summary in Foreign language or Hungarian

Csorba Ádám, Szegi Tamás, Fuchs Márta, Gulyás Miklós, Holes Annamária, Fenyvesi László, Michéli Erika
Investigation of spectral properties of high organic matter content wastes and soil-waste complexes
In: ORBIT 2014 Scientific Conference: 9th Conference on Organic Resources and Biological Treatment. Konferencia helye, ideje: Gödöllő, Magyarország, 2014.06.26-2014.06.28.p. 8. 1 p. **(2pont)**

Czinkota I, Keresztes, Simándi Péter, Rácz, Rétháti Gabriella, Gulyás Miklós, Tolner László
Analysis of organic matter and heavy metal extraction kinetics of different pyrolized waste fractions
In: ORBIT 2014 Scientific Conference: 9th Conference on Organic Resources and Biological Treatment. Konferencia helye, ideje: Gödöllő, Magyarország, 2014.06.26-2014.06.28.p. 43. 1 p. **(2pont)**

Füleky Gy, Gulyás M, Fuchs M, Holes A, Kocsis I, Puskás J
Effects of solid pyrolysis products on the soil and plant properties in laboratory experiment
In: Marianne Bell (szerk.)
20th International Symposium on Analytical & Applied Pyrolysis: Pyro2014. Konferencia helye, ideje: Birmingham, Egyesült Királyság, 2014.05.19-2014.05.23.p. 63. 1 p. **(2pont)**

Holes Annamária, Szegi Tamás, Fuchs Márta, Gulyás Miklós, Aleksza László
Komposzttal, bioszénnel és kalcium karbonáttal kezelt homoktalajok hatásának vizsgálata homoktalajok kémiai tulajdonságaira, különös tekintettel a szervesanyagok oldhatóságára
In: Sisák István, Homor Anna, Hernádi Hilda (szerk.)
Talajtani Vándorgyűlés: A talajok térbeli változatossága - elméleti és gyakorlati vonatkozások. Konferencia helye, ideje: Keszthely, Magyarország, 2014.09.04-2014.09.06. (Pannon Egyetem Georgikon Kar)
Veszprém: Pannon Egyetemi Kiadó, pp. 111-112. **(1pont)**

Miklós Gulyás, Márta Fuchs, Annamária Holes, Tamás Szegi, István Kocsis, György Füleky

EFFECTS OF DIFFERENT BIOCHARS AND COMBINED BIOCHAR AND ANAEROBIC DIGESTATE UTILIZATION ON RYE-GRASS AND SOIL PROPERTIES IN LABORATORY EXPERIMENT
In: ORBIT 2014 Scientific Conference: 9th Conference on Organic Resources and Biological Treatment. Konferencia helye, ideje: Gödöllő, Magyarország, 2014.06.26-2014.06.28.p. 46. 1 p. **(2pont)**

Gulyás Miklós, Szegi Tamás, Füleky György
Pot experiments with anaerobic digestate (summary)
In: BCD 2013 Biochars, Composts and Digestates. Production, Characterization, Regulation, Marketing, Uses and Environmental Impact. Konferencia helye, ideje: Bari, Olaszország, 2013.10.17-2013.10.20. Bari: p. 174. 1 p. **(2pont)**

Marianna Makádi, Judit Berényi-Üveges, Attila Tomócsik, Miklós Gulyás, Tamás Szegi
THE EFFECTS OF INGESTATES COMPOSITIONS ON THE QUALITY OF LIQUID DIGESTATES
In: BCD 2013 Biochars, Composts and Digestates. Production, Characterization, Regulation, Marketing, Uses and Environmental Impact. Konferencia helye, ideje: Bari, Olaszország, 2013.10.17-2013.10.20. Bari: Paper 190. **(2pont)**

Miklós Gulyás, György Füleky
Effects of biogas digestate on soil properties and plant growth
In: European Geosciences Union General Assembly 2013. Konferencia helye, ideje: Bécs, Ausztria, 2013.04.07-2013.04.12.p. Paper 2797. 1 p. **(2pont)**

Gulyás M, Szegi T, Makádi M, Füleky Gy
Effects of digestate application on chemical properties of soil
In: Senesi N (szerk.)
EUROSOIL 2012 - 4th International Congress of the European Confederation of Soil Science Societies. Konferencia helye, ideje: Bari, Olaszország, 2012.06.02-2012.06.06. Bari: p. 1471. **(2pont)**

References

Ali Mekki, Fatma Arous, Fathi Aloui, Sami Sayadi (2013): Disposal of agro-industrials wastes as soil amendments, American Journal of Environmental Science 9 (6): 458-469

Anna Piotrowska, Giuseppina Iamarino, Maria Antonietta Rao, Liliana Gianfreda (2006): Short-term effects of olive mill waste water (OMW) on chemical and biochemical properties of a semiarid Mediterranean soil, Soil Biology and Biochemistry, Volume 38, Issue 3, March 2006, Pages 600-610

Balla Alajosné (1963): Az istállótrágyázás és a műtrágyázás hatásának összehasonlítása vetésforgó trágyázási kísérletben, Agrokémia és Talajtan 12 (1963)

Edward Someus (2016): FAQ - Frequently Asked Questions: Pyrolysis – Biochar – Bonechar– Phosphorus

Kádár I., Petróczki F., Hámori V., Morvai B. (2009): Kommunális szennyvíziszap, illetve vágóhídi hulladék komposzt hatása a talajra és a növényre szabadföldi kísérletben, Agrokémia és Talajtan 58 (2009) 1 121–136

Kovács D., Kardos Gy., Füleky Gy. (2005): A feltárás és a komposztálás hatása a csontok trágyaszerként történő alkalmazhatóságára, Agrokémia és Talajtan 54 (2005) 3–4 427–438

L. Van Zwieten, S. Kimber, S. Morris, K. Y. Chan, A. Downie, J. Rust, S. Joseph, A. Cowie (2010): Effects of biochar from slow pyrolysis of papermill waste on agronomic performance and soil fertility, Plant and Soil, February 2010, Volume 327, Issue 1, pp 235–246

Lásztity Borivoj (1986): Néhány elem koncentrációjának változása az őszi rozsban és a triticalében a tenyészidő folyamán. Agrokémia és Talajtan 35. (1986) No. 1-2., 85-94 p.

Ndayegamiye, A. and Coté, D. (1989). Effect of long-term pig slurry and solid cattle manure application on soil chemical and biological propenies. Can. J. Soil Sci.69: 39-47.

Revell, K. T., Maguire, R. O., Agblevor, F. A., 2012. Influence of Poultry Litter Biochar on Soil Properties and Plant Growth. Soil Science, 177 (6): 402-408.

Robinson, J. B., & Reuter, D. J. (1997). Plant analysis: An interpretation manual. Melbourne: Commonwealth scientific and industrial research organization.

Roger Nkoa (2014): Agricultural bene ts and environmental risks of soil fertilization with anaerobic digestates: a review. Agronomy for Sustainable Development, 2014, 34 (2), pp.473-492.

Somosné N. A., Szolnoky T. (2009): A biogáz-üzemi kierjedt fermentlé hasznosítása. Agrokémia és Talajtan 58.kötet 2. szám p. 381-386

Stefanovits P., Filep Gy., Füleky Gy. (1999): Talajtan. Mezőgazda Kiadó p.196

Tomócsik A., Makádi M., Márton Á., Lengyel J. (2007c): Tápanyag-utánpótlás biogázüzemi fermentlével. Biohulladék 2: 4 p. 22-24.

Vágó I., Makádi M., Kátai J., Balláné K. A. (2008): A biogáz gyártás melléktermékének hatása a talaj néhány kémiai tulajdonságára. Talajvédelem, Supplementum. Talajtani Vándorgyűlés, Nyíregyháza. p. 555-560.