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Digestate: A New Nutrient Source – Review

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1. Introduction

Digestate is the by-product of methane and heat production in a biogas plant, coming from organic wastes. Depending on the biogas technology, the digestate could be a solid or a liquid material.

Digestate contains a high proportion of mineral nitrogen (N) especially in the form of ammonium which is available for plants. Moreover, it contains other macro- and microelements necessary for plant growth. Therefore the digestate can be a useful source of plant nutrients, it seems to be an effective fertilizer for crop plants. On the other hand, the organic fractions of digestate can contribute to soil organic matter (SOM) turnover, influencing the biological, chemical and physical soil characteristics as a soil amendment.

Besides these favourable effects of digestate, there are new researches to use it as solid fuel or in the process of methane production.

2. Origin of digestate

For protection of the environment, the recycling of organic materials has essential role. The anaerobic digestion (AD) is an important method to decrease the quantity of organic wastes by utilization them for energy and heat production. The by-product of this process is the digestate.

In an AD process, different organic materials could be used alone or in mixture of animal slurries and stable wastes, offal from slaughterhouse, energy crops, cover crops and other field residues, organic fraction of municipal solid wastes (OFMSW), sewage sludge. The quality of digestate as a fertilizer or amendment depends not only on the ingestates but also on the retention time. The longer retention time results in less organic material content of the digestate because of the more effective methanogenesis (Szűcs et al., 2006).

Biogas technology is known to destroy pathogens. The thermophilic AD increases the rate of elimination of pathogenic bacteria, therefore the amounts of fecal coliforms and enterococcus fulfilled the requirements of EU for hygienic indicators (Paavola & Rintala, 2008). Mesophilic digestion alone may not be adequate for correct hygienization, it needs a separate treatment (70 ^{o}C, 60 min., particle size<12 mm) before or after digestion, especially in the case of animal by-products (Bendixen, 1999; Sahlström, 2003).

Two types of digestate are the liquid and the solid ones which are distinguished on the bases of their dry matter (DM) content. The liquid digestate contains less than 15% DM content, while the solid digestate contains more than 15% DM. Solid digestate can be used similar to the composts or could be composted with other organic residues and can be more economically transported over grater distances than the liquid material (Møller et al., 2000).

3. Composition of digestate

The quality of a digestate is determined by the digestion process used and the composition of ingestates therefore the agricultural use and efficacy of the nascent materials could be different. Nevertheless, some common rules can be found in the course of the digestion process which allow us to evaluate the results of a digestion process.

3.1 pH of digestate

Generally, the pH of digestate is alkaline (Table 1). Increases in pH values in the course of the AD may have been caused by the formation of $(NH_4)_2CO_3$ (Georgacakis et al., 1992).

Type of ingestate	Type of digestion process	pH of ingestate	pH of intermedier stage	pH of digestate	Source of data
Pharmaceutical industry sludge	mesophilic, solid type digester	7.0	7.5	7.8	*Gómez et al., 2007*
Cattle manure	mesophilic, liquid type digester	6.9	7.2	7.6	*Gómez et al., 2007*
Primary sludge from municipal waste water treatment plant and organic fractions of municipal solid wastes	thermophilic (co-digestion), liquid type digester	3.5	5.0	7.5	*Gómez et al., 2007*
Energy crops, cow manure slurry and agro-industrial waste	thermophilic (co-digestion), liquid type digester	4.8	7.5	8.7	*Pognani et al., 2009*
Energy crops, cow manure slurry, agro-industrial waste and OFMSW	thermophilic (co-digestion), liquid type digester	4.0	8.1	8.3	*Pognani et al., 2009*

Table 1. Changes of the pH in different digestion systems

The pH is increased under the digesting process, but its range depends on the quality of ingestate and the digestion process. The end values are irrespective of the starting value.

The alkaline pH of digestate is a useful property because of the worldwide problem of soil acidification.

3.2 Macroelement content of digestate

The other characteristics of digestate also are differed depending on the source materials and the digestion process. In Table 2 some major properties of different liquid digestates can be seen, but these are mean values which could be altered in the course of the digestion process. Therefore regular monitoring of digestate properties is needed in the case of its agricultural use.

Type of ingestate	Type of digestion process	Total-N (N_t)	NH_4-N	Total-P	Total-K	Source of data
Swine manure	mesophilic	2.93 (g L^{-1})	2.23 (g L^{-1})	0.93 (g L^{-1})	1.37 (g L^{-1})	*Loria et al., 2007*
Liquid cattle slurry	mesophilic	4.27 (% DM)	52.9 (‰ N_t)	0.66 (% DM)	4.71 (% DM)	*Möller et al., 2008*
Energy crops, cow manure slurry and agro-industrial waste	thermophilic	105 (g kg^{-1} TS)	2.499 (g L^{-1})	10.92 (g kg^{-1} TS)	-	*Pognani et al., 2009*
Energy crops, cow manure slurry, agro-industrial waste and OFMSW	thermophilic	110 (g kg^{-1} TS)	2.427 (g L^{-1})	11.79 (g kg^{-1} TS)	-	*Pognani et al., 2009*
Cow manure, plant residues and offal	mesophilic and thermophilic	0.2013 (%m/m, fresh matter)	0.157 (%m/m, fresh matter)	274.5 mg kg^{-1} (fresh matter)	736.45 mg kg^{-1} (fresh matter)	*Makádi et al.,2008b*
Clover/grass or pea straw or cereal straw or silage maize and clover/grass silage (mean)	mesophilic	0.253 (%m/m, fresh matter)	0.176 (%m/m, fresh matter)	0.62 (% DM)	18.5 (% DM)	*Stinner et al., 2008*

Table 2. Characteristics of liquid digestates from different origin

Nitrogen (N) is a major plant nutrient and is the most common plant growth limiting factor of agricultural crops. The fertilizing effect of added N is decreased by the inadequate synchrony of crop N demand and soil N supply (Binder et al., 1996; Möller & Stinner, 2009). The advantage of digestate application is the possibility of reallocation of the nutrients within the crop rotation from autumn to spring, when crop nutrient demand arises (Möller et al., 2008). The higher N content of a digestate comparing to the composts is the consequence of the N concentration effect because of carbon degradation to CO_2 and CH_4 and N preservation during AD (Tambone et al., 2009).

The NH_4 content of the digestate is about 60-80% of its total N content, but Furukawa and Hasegawa (2006) reported 99% of NH_4-N of the digestate originated from kitchen food wastes. Generally, the NH_4-N concentration is increased by the protein-reach feedstock (Kryvoruchko et al., 2009) like diary by-products and slaughterhouse waste (Menardo et al., 2011). The conversion of organic N to NH_4-N allows its immediate utilization by crops (Hobson and Wheatley, 1992). The higher amount of NH_4-N and the higher pH predominate over the factors (lower viscosity, lower dry matter content) which could reduce the ammonia volatilization from the digestate (Möller & Stinner, 2009). The emission of ammonia could be decreased by different injection techniques which lower the air velocity above the digestate and because of the bound of gaseous ammonia to soil colloids and soil water (McDowell and Smith, 1958). The application depth has a significant effect on ammonia volatilization. Surface application of a liquid biofertiliser caused the loss of 20-35% of the applied total ammoniacal N while disc coulter injection into 5-7 cm depth reduced the ammoniacal loss to 2-3% (Nyord et al, 2008). This method should be used also in the case of digestate application to reduce ammonia volatilization.

Digestate has higher phosphorus (P) and potassium (K) concentration than that of composts (Tambone et al., 2010) therefore it is more suitable for supplement of these missing macronutrients in soils. Furthermore, Börjesson and Berglund (2007) assumed all phosphorus in the digestate to be in available forms, therefore digestate seems to be a useful material for supplement missing nutrients of soil, especially of the P and K. The average phosphorus-potassium ratio of digestates is about 1:3 which is excellent for grain and rape. Accumulation of P and K in soil could be avoided by the reduction of the applied digestate dose but in this case, for the supplement of nitrogen gap, the artificial fertilizer has to be used.

3.3 Microelement content of digestate

Plants, animals and humans require trace amounts of some heavy metals like copper (Cu), zinc (Zn), while others like cadmium (Cd), chromium (Cr), mercury (Hg), lead (Pb) are toxic for them. Heavy metal content of the feedstock usually originates from anthropogenic source and is not degraded during AD. The main origins of the heavy metals are animal feed additives, food processing industry, flotation sludge, fat residues and domestic sewage.

With a N load of 150 kg ha^{-1}, the heavy metals load into the soil (Cd, Cr, Cu, Ni, Pb, Zn) were lower in the case of digestate addition comparing to the compost and sewage sludge treatments while were higher in some heavy metals (Cu, Ni, Pb, Zn) comparing to the mineral fertilizer (Pfundtner, 2002).

3.4 Organic matter content of digestate

The amounts of organic dry matter and the carbon content of digestate are decreased by the decomposition of easily degradable carbon compounds in the digestors (Stinner et al., 2008). Menardo et al. (2001) found the degree of organic matter (OM) degradation between 11.1%

and 38.4% in the case of different ingestates, highest loading rates and hydraulic retention times while Marcato et al. (2008) found this value of 53%. If the organic loading rate of biogas plant is high and the hydraulic retention time is short, the digestate will contain a considerable amount of undigested OM, which is not economic and not results a good amendment material. However, the OM content of digestate is more recalcitrant and therefore the microbial degradation and soil oxygen consumption can be decreased by its application (Kirchmann & Bernal, 1997).

The adequacy of digestate as soil amendment is based on its modified OM content. Most OM is converted into biogas, while the biological stability of remaining OM was increased during AD with the increase of more recalcitrant molecules like lignin, cutin, humic acids, steroids, complex proteins. These aliphatic and aromatic molecules are possible humus precursors with high biological stability (Tambone et al., 2009). Pognani et al. (2009) found the increase of these macromolecules' quantities in the course of AD as it can be seen in Table 3.

Type of ingestate	Total solid (TS) ($g\ kg^{-1}$ ww)		Lignin ($g\ kg^{-1}$ TS)		Hemicelluloses ($g\ kg^{-1}$ TS)		Celluloses ($g\ kg^{-1}$ TS)	
	Inge-state	Dige-state	Inge-state	Dige-state	Inge-state	Dige-state	Inge-state	Dige-state
Energy crops, cow manure slurry and agro-industrial waste	127	35	49	280	35	42	50	68
Energy crops, cow manure slurry, agro-industrial waste and OFMSW	143	36	72	243	27	54	71	79

Table 3. Changes in macromolecules content on the course of AD *(Data from Pognani et al., 2009)*

Similarly, the rate of lignin-C, cellulose-C and hemicellulose-C are increased in the organic matter content after AD of cattle and pig dung (Kirchmann & Bernal, 1997). The increase of these macromelecules-C were 2.4-26.8 %, 14.2-13.9 % and 7.3 % in the manures, respectively. The hemicellulose-C content in the anaerobically treated pig dung was decreased by 23.8 %. However, the increase of non-decomposable carbon content of digestate is always smaller than that of composts (Gómez et al., 2007). On the other hand, improving the fertilizer effect of a digestate with its higher decomposable carbon content results in an increase in roots and crop residues which may have an important effect on the soil organic matter content.

4. Effects of digestate on soil properties

Digestate is a very complex material therefore its using has effect on the wide range of physical, chemical and biological properties of the soil, depending on the soil types (Makádi et al., 2008). The recycled organic wastes are suitable for contribution to maintain the soil nutrient levels and soil fertility (Tambone et al., 2007). Among the organic amendments the ratio of liquid digestate in the agriculture is known to be around of 10%. It can be applied as a fertilizer, but it could be appropriate as a soil quality amendment (Schleiss and Barth, 2008). Comparing to the other organic materials, the amendment properties rank sequentially as compost ~ digestate > digested sludge >> ingestate, on the bases of OM degradability (Tambone et al., 2010).

4.1 Effect of digestate on soil pH

Odlare et al. (2008) have not found significant change in the pH after 4-year-long biogas residue application rate. The pH of soils were 5.6 and 5.7 in the control and biogas residue treated samples, respectively. Similar results were reported by Fuchs & Schleiss (2008), because they have found an enhance of soil pH for about ½ unit after harvesting of maize. Because of the alkaline pH of digestates, an increase of the soil pH should be supposed. However, digestate might contain various acidic compounds (e.g. gallic acid). The polycondensation, connection to organic and inorganic colloids and transformation of these acids can have an effect also on the soil chemical properties and finally the decrease of soil pH (Tombácz et al., 1998, 1999), more particularly at the soils with high organic and inorganic colloid contents. Therefore the regular monitoring of soil pH is necessary in case of long-term digestate application.

4.2 Effect of digestate on soil macroelement content

One of the main problem of digestate (and other N fertilizer) application is the N leaching. However, Renger & Wessolek (1992) and Knudsen et al. (2006) found that the N leaching was dependent on the use of cover crops. Similar results were reported by Möller & Stinner (2009) who did not find differences in the soil mineral N content among different manuring systems in the case of winter wheat, rye and spelt in autumn, before use of cover crops. That means that the use of cover crops is an appropriate method to avoid N leaching and to compensate for higher N application. From the same experiment, Möller et al. (2008) reported average soil mineral N content in spring. In this case they found significant higher soil mineral N content of the digested slurry treated samples (Table 4).

Treatments	Soil mineral N (kg N ha^{-1}), 0-90 cm soil layer
Farmyard manure	65.7 a
Undigested slurry	71.1 ab
Digested slurry	89.2 c
Digested slurry + field residues	81.3 bc
Digested slurry + field residues + clover/grass and silage maize mixture	83.6 bc

Table 4. Average soil mineral N content in spring in 0-90 cm with the main crops spelt, rye and spring wheat from 2003-2005 *(Data from Makádi et al., 2007).* a, b, c indexes mean the different values (P<0.05).

Digestate contains high proportion of NH_4-N therefore it would be expected to increase NH_4-N content of treated soil. However, digestate applied in the fall could easily be nitrified by early spring (Rochette et al., 2004; Loria et al., 2007). This predisposed N loss with occurrence of wet conditions.

Generally, the digestate application does not cause any significant changes in the total-N and available P content, while the available K content was increased by the application of biogas residue (Olsen et al., 2008). Similar results have found Vágó et al. (2009), who reported the significant increase of 0.01 M dm^{-3} $CaCl_2$ extractable P content even after 5 L m^{-2} digestate treatment, while the K content of soil was significantly increased by 10 L m^{-2} digestate dose only.

4.3 Effect of digestate on soil microelement

After the application of the digestate in 5 and 10 L ha^{-1} dosages, the Cd, Co, Cu, Ni and Sr content of soil solutions did not change. The Zn content decreased significantly, while the amount of manganese (Mn) increased by almost 40% (Vágó et al., 2009) (Table 5).

Element	Control	5 L ha^{-1} digestate	10 L ha^{-1} digestate
Cd	0.063	0.067	0.055
Co	0.064	0.071	0.057
Cu	0.089	0.112	0.118
Mn	25.5	35.1	35.5
Ni	0.50	0.52	0.35
Sr	8.56	8.60	8.62
Zn	1.40	0.98	0.062

Table 5. Microelement content of soil samples (mg kg^{-1}) treated with liquid digestate (extraction with 0.01 M dm^{-3} $CaCO_3$). (*Data from Vágó et al., 2009*).

The increasing soluble P content of digestate treated soil decreased the available Zn content in the soil solution by building slightly soluble zinc-phosphate residue (Vágó et al., 2009).

4.4 Effect of digestate on soil organic matter content

Soil OM decreases in crop soils in Europe and in other continents therefore using amendments for increasing the soil OM content has a particular interest.

Digestate contains high amount of volatile fatty acid (C2-C5) which could be decomposed within few days in the soil (Kirchmann & Lundwall, 1993). The greatest rate of decomposition were observed in the first day after the treatment (Marcato et al., 2009) but the mineralization rate were high during the first 30 days (Plaza et al., 2007). Moreover, the C-mineralization values from the soil incubation assay showed that the results of raw slurry were similar to the effect of compost being in the start of composting process while the digested slurry had similar C-mineralization rate in the soil samples than that of the matured compost (Marcato et al., 2009).

4.5 Effect of digestate on the microbiological activity of soil

Soil microbial community has an important role in the fertility of soil and its alteration after intervention to the soil (e.g. manuring, soil improving, soil pollution) could be indicate more sensitive these changes than changes in the soil physical and chemical properties.

Among the different organic wastes like compost, biogas residue, sewage sludge and different manures with and without mineral N, the biogas residue was more efficient for promoting the soil microbiological activity. The high amount of easy-degradable carbon increased the substrate induced respiration (SIR), which was enhanced by the higher carbon content resulted from the higher litter and root exudates of higher plant growth. In accordance with these results, the largest proportion of active microorganisms was found in the digestate treated samples (Odlare et al., 2008; Kirchmann, 1991). Similarly, the activity of invertase was significantly higher in the digestate treated samples than that in control ones (Makádi et al., 2006).

Besides the macro- and micronutrient content of digestate which are important not for the crops but for soil microorganisms too, it contains growth promoters and hormones, also. Therefore it could be used for stubble remains to facilitate their decomposing. Makádi et al. (2007) compared the effect of digestate and Phylazonit MC bacterial manure on the growth of silage maize (*Zea mays* L. 'Coralba') as a second crop after winter wheat and on the enzyme activities of soil. Digestate was used at the rate of 50% of the total N demand of silage maize while the Phylazonit MC was used at 5 L ha^{-1} dose. Their results of the changes in enzyme activities are summarized in Table 6.

Treatments	Enzyme activity (mean±S.D.)	
	16/08/2006.	27/09/2006
Invertase activity (mg glucose 1 g^{-1}soil 4 h^{-1})		
a) Control	5,618±1,392^{a}	3,767±2,030^{b}
b) Phylazonit MC	7,437±1,945^{a}	4,095±0,901^{b}
c) Phylazonit MC+digestate	6,613±2,230^{a}	1,584±0,748^{a}
d) Digestate	6,024±1,486^{a}	6,206±0,997^{c}
Catalase activity (mg O_2 1 g^{-1} dry soil 1 h^{-1})		
a) Control	1,468±0,118^{b}	1,797±0,289^{b}
b) Phylazonit MC	1,160±0,144^{ab}	1,410±0,050^{a}
c) Phylazonit MC+digestate	0,983±0,275^{a}	1,205±0,117^{a}
d) Digestate	1,961±0,395^{c}	1,288±0,063^{a}

Table 6. Invertase and catalase activities of soil on the 3rd and 9th week after digestate and Phylazonit MC treatment (*Data from Makádi et al., 2007*). a, b, c indexes mean the different statistical groups according to Tukey's test ($p<0.05$).

The maximum of the degradation of disaccharides, indicated by the invertase activity, was found in the 3rd week after Phylazonit MC treatment, while it was found only after the 9th week in the digestate treated soil samples. The Phylazonit MC contains only bacteria and promoting agents of bacterial activity for degrading the soil OM. Contrarily, in the digestate treated samples the degradation of disaccharides takes place at similar rate through 9 weeks because of the OM content of digestate used. Changes in catalase activity indicate the effect of nutrient content of digestate to the increasing microbial metabolism.

5. Effects of digestate on crop yield

On the bases of the plant reaction on the digestate treatment, plants could be classify into the sensitive (alfalfa, sunflower, soybean) and the non-sensitive (winter wheat, triticale, sweet corn, silage maize) groups. The sensitive plants can be treated by digestate only in their certain life stages, for example, young alfalfa is very sensitive after sowing while old alfalfa is very sensitive before cutting. In the case of sensitive plants the burning effect of digestate can be observed but it follows a strong and quick recovering process. For the non-sensitive plants the digestate can be used in any developmental stage. It is favourable, because for example, in rainy period the digestate technically could not be applied (Makádi et al., 2008).

The right application rate of liquid or solid digestate depends on the plant nitrogen demand. It should be applied when plant N demand arises. This time for non-legume scpecies is the late winter and spring (Stinner et al., 2008). Similarly, Wulf et al. (2006) used 70% of the digestate in spring and 30% in autumn, while Makádi et al. (2008) and Nyord et al. (2008) split into two and three the applied rate through the vegetation period.

Because of its high available nutrient content, digestate application resulted in significantly higher aboveground biomass yields in the case of winter wheat and spring wheat than the farmyard manure and undigested slurry treatment. The effectiveness of a digestate depends on the composition of co-digestied material, the treated plant species and the treatment methodology. Co-digestion of different organic materials results in more effective digestate. (Möller et al., 2008; Stinner et al., 2008).

After the burning effect of digestate the soybean plants recovered and grew more, but lower sprouts. These sprouts were very productive, the number of pods was also higher in the treated samples, therefore the yield and thousand seed weight were also higher (Table 7, Makádi et al., 2006)

Digestate (L m^{-2})	Height of plants (cm)	Weight of sprout (g m^{-2})	Weight of pods (g m^{-2})	Weight of grain (g m^{-2})	Thousand seed weight (g)
	mean±S.D.				
0	74.3± 1.15a	218.0± 33.08a	351.2± 69.69a	233.2± 40.61a	134.3± 1.71a
5	71.8± 2.68a	214.4± 4.98a	521.0± 20.30b	335.2± 43.46b	172.2± 6.61b
10	70.2± 7.73a	234.4± 7.73a	811.0± 33.09c	566.5± 25.05c	191.0± 8.69c

Table 7. Yield parameters of soybean after digestate treatment (*Data from Makádi et al., 2008).* a, b, c indexes mean the different statistical groups according to Tukey's test ($p<0.05$).

These yield parameters are close correlations with some soil parameters changing after digestate amendment. Increasing in important nutrient contents contribute to the better development of plants (Makádi et al., 2008b, Table 8).

Comparing the effect of liquid digestate and the equal quantity of water to the yield of sweet corn and silage maize, significantly higher yields were found in the digestate treatment. In this case the applied digestate on the bases of plants N demand was split into two parts (Makádi et al., 2006). That means that the favourable effects of digestate are caused by its soluble macro- and micronutrient content.

		NO_3-N	AL-P	AL-K	AL-Mg
Number of pods	Pearson Corr.	0.712*	0.798*	0.622	0.850**
	Sig. (2-tailed)	0.031	0.01	0.074	0.004
Weight of pods	Pearson Corr.	0.755*	0.824**	0.693*	0.839**
	Sig. (2-tailed)	0.019	0.006	0.039	0.005
Weight of grain	Pearson Corr.	0.742*	0.832**	0.739*	0.810**
	Sig. (2-tailed)	0.022	0.005	0.023	0.008
Thousand seed weight	Pearson Corr.	0.695*	0.690*	0.827**	0.595
	Sig. (2-tailed)	0.038	0.040	0.006	0.091

* Correlation is significant at the 0.05 level; ** Correlation is significant at the 0.01 level.

Table 8. Correlations between soil and plant parameters in digestate treatment experiment. (*Data from Makádi et al., 2008b)*

Comparing the effect of digestate and a bacterial manure (Phylazonit MC, the experimental conditions can be found in the section 4.5). The Phylazonit MC treatment increased the green weight of silage maize by 47.18% while the digestate by 142.34%, comparing to the control. The results obtained can be seen in Table 9 (Makádi et al., 2007).

Treatments	Green weight, t ha^{-1} mean±S.D.
Control	6,448±2,580^{a}
Phylazonit MC	9,490±4,081^{ab}
Phylazonit MC + digestate	13,997±0,493^{bc}
Digestate	15,626±2,293^{c}

Table 9. Green weight of silage maize as a second crop after digestate and Phylazonit MC treatment of stubble. (*Data from Makádi et al., 2007*). a, b, c indexes mean the different statistical groups according to Tukey's test ($p<0.05$).

The positive effect of Phylazonit MC treatment was the result of its microbes, plant growth promoters and microelement content, while the favourable effect of digestate treatment was caused by its macro- and microelement and high water content and the increase of soluble macroelement content of soil because of the increased microbial activity.

6. Effects of digestate on the quality of crops

Crop yield is very important economical parameter of plant production but nowadays the quality of foods is becoming more and more important. Digestate treatment seems to be very effective to increase the protein content of plants. Banik and Nandi (2004) investigated biogas residual slurry manures (solid digestate) used as supplement with rice straw for preparation of mushroom beds. The application of biomanure increased the protein content of mushroom 38.3-57.0%, while the carbohydrate concentrations were decreased. Results can be seen in Table 10.

Similar results were reported by Makádi et al., (2008b) who found significant increase of protein content of treated soybean. They have found 30.65±1.42% protein in control plants, while these values were 34.83±1.50% and 35.67±1.81% for 5 and 10 L m^{-2} treatments, respectively. Changes in amino acid composition of test plants were also very favourable, because almost every essential and non-essential amino acid quantity was increased significantly after digestate treatment. In line with these results the oil content of the treated plants decreased significantly.

Treatments	Protein (%)	Carbohydrate (%)	Lipid (%)	Increase of protein over control (%)
Straw (100%)	21.56	28.81	10.43	0
Straw + cowdung biomanure	29.81	20.21	13.73	38.3
Straw + poultry litter biomanure	33.57	21.45	7.96	55.7
Straw + jute caddis biomanure	33.84	21.79	13.93	57.0

Table 10. Effect of supplementation of rice straw with solid digestate on major nutrient contents of mushroom (*Pleurotus sajor caju*). (*Data from Banik and Nandi, 2004*)

Qi et al (2005) examined the effect of fermented waste as organic manure in cucumber and tomato production in North China. Before the vegetables transplantation, the diluted fermented residual dreg was applied 20-30 cm below the soil surface at a rate of 37,500 kg ha^{-1}, while liquid digestate was sprinkled to the soil surface in three vegetables growing stages and on the vegetable leaves once time. They found increasing yield (18.4% and 17.8%) and vitamin C content (16.6% and 21.5%) of treated cucumber and tomato, respectively.

As the results show, the digestate application in solid or liquid form could result significant improvement in the quality of foods without damaging the environment, which is very important for the sustainable environment and healthy life.

7. Legislation of digestate utilization in agriculture

Sustainable recycling of organic wastes demands clear regulations of recycled wastes, the used recycling methods and the controlling of products. These regulation processes for the digestate are different in certain countries, respected the elaboration and the used limits.

In Hungary, the digestate is regarded as other non-hazardous waste if the ingestate does not contain sewage or sewage sludge, while in the presence of these materials the conditions of the digestate utilisation depend on the quality of the given material.

In Scotland the BSI PAS110:2010 digestate quality assurance scheme is applied. If a digestate complies with the standards for the quality, the usage criteria and the certification system stated in the worked scheme, the Scottish Environment Protection Agency (SEPA) does not apply the waste regulatory control for it.

In Swiss the digestate which suits the limits, can be used as soil conditioner and fertilizer in "bio"-agriculture.

In Germany the origin of the input materials determines the quality label of digestate product by biowaste and renewable energy crops. Digestates have to fulfil the minimum quality criteria for liquid and solid types which determine the minimum of nutrients and the maximum of pollutions in the digestate. Pollutions mean toxic elements, physical contaminants and pathogen organisms. The quality of digestate products is regularly controlled by "Bundesgütegemeinschaft Kompost e.V." (BGK) (Siebert et al., 2008).

8. Future prospects

Beside the fertilizer or amendment properties of digestate, nowadays there are some other ways to utilize it. These new methods are very creative and make the possibility of proper utilization of digestates with different quality.

A new promising alternative of the digestate utilization is its use as solid fuel after drying. Kratzeisen et al. (2010) used liquid digestate originated from silage maize co-digestion with different field crops and animal residues. After drying the digestate, the water content of pellets made was 9.2-9.9%. Their mechanical durability fulfilled the requirements of standards for pellets. Moreover, the calorific value of these pellets was similar to the calorific value of wood. Therefore digestate fuel pellet seems to be a good alternative fuel for wood.

Another interesting possibility of digestate utilization is the using of digestate effluent to replace freshwater and nutrients for bioethanol production. Gao & Li (2011) found that ethanol production was enhanced with digestate effluent by as much as 18% comparing to the freshwater utilization.

Digestate can be separated to liquid and solid fraction. Liquid fraction is suitable for irrigation and it has high N and K content. Solid fraction contains a great amount of volatile solid and P (Liedl, et al., 2006) and – by its fertilizer effect – has also high biogas and methane potential, therefore it could be used as a co-ferment for anaerobic digestion (Balsari et al., 2009)

9. Conclusion

The use of anaerobic digestion for treatment of solid and liquid organic wastes has vastly increased world-wide. The by-product of this process is the digestate, a liquid or solid material with high nutrient and organic matter content. These properties of the digestate make possible to use it as plant nutrients and to characterize it as a fertilizer. On the other hand, a biomass, reach in recalcitrant molecules is characterized by a high biological stability degree which is suitable for soil improving. The utilization of digestate as fertilizer provides economic and environmental benefits because of its higher stabile organic matter content, the hygienization effect of anaerobic digestion process and the reduced quantity of the artificial fertilizers needs for plant production. Moreover, the alkaline pH of digestate could contribute to the decrease of soil acidification, which is a serious problem of the world. Using digestate in place of artificial fertilizers could contribute to maintain the fertility of soil.

As the results show, the digestate application in solid or liquid form could result significant improvement of the quantity and quality of foods through the even nutrient supply harmonizing with the necessity of plants and through its microelement content in the available forms for plants. In this way, digestate application in agriculture could contribute to the healthy life of humans.

Microbiological activity of soil could be increased by application of digestate which is also an important condition of soil fertility.

Beyond these "classical" application possibilities of digestate, there are new promising alternatives for its utilization which means more opportunities to use this valuable matter for making better our environment and our life.

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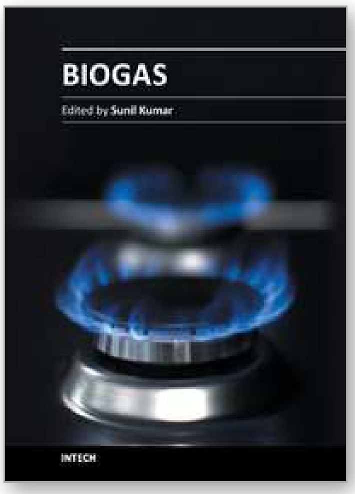

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This book contains research on the chemistry of each step of biogas generation, along with engineering principles and practices, feasibility of biogas production in processing technologies, especially anaerobic digestion of waste and gas production system, its modeling, kinetics along with other associated aspects, utilization and purification of biogas, economy and energy issues, pipe design for biogas energy, microbiological aspects, phyto-fermentation, biogas plant constructions, assessment of ecological potential, biogas generation from sludge, rheological characterization, etc.