TESTING THE IMPACT OF WASTE FROM ANAEROBIC DIGESTION (ENRICHED WITH AN ORGANIC COMPONENT) ON THE QUALITY OF AGRICULTURAL LAND

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Abstract

Waste from anaerobic digestion is considered as a mineral fertilizer and it is usually applied to agricultural land. The aim of our attempt was to enrich this waste from anaerobic digestion (digestate) with an organic component (in our case represented by haylage). For this purpose, we made different mixtures of digestate and haylage in different weight ratios. In the field trial, the effect of these mixtures on the soil, under standard agricultural conditions, was monitored. Selected accessible nutrients (P, K, Mg, Mn, Ca) and the amount of carbon and nitrogen in the soil were monitored. The results of the laboratory tests confirmed that the areas where the sowing and digestate mixtures were applied showed greater amounts of macro- and micronutrients in plant-accessible forms than the surface fertilized only with digestate or areas fertilized only with standard fertilizers.

Keywords: biogas plant, biogas, whole digestate, macronutrients, micronutrients

1 INTRODUCTION

In the past twenty years there has been a significant development of biogas stations within the Czech Republic. According to the Czech biogas association, more than 550 biogas stations are currently registered. This development is supported by fixed tariffs for the purchase of energy from non-renewable sources (Directive 2009/28/EC, 2009) and by Directive 1999/31, which aims to reduce biodegradable waste in landfills by 35% by 2020.

The final product of the biogas plant is both the produced energy (in the form of electricity and heat) and the waste product called digestate. According to Frost and Gilinson (2011), an average 1,320 kWh/day biogas plant produces an average of 19.8 tonnes of digestate/day (460 kWh in the form of electricity and 860 kWh in the form of thermal energy). That means about 7,227 tonnes of digestate is produced per year. And all the digestate must be handled.

In the Czech Republic, digestate is treated as a mineral fertilizer which is, in the growing season, incorporated into the soil (in accordance with the framework of European Directive 91/676/EEC, and as regards the Czech legislation, within the framework of Act No. 262/2012 Coll. in the current version). Both documents concern the protection of aquatic ecosystems from pollution (so-called eutrophication). Opinions on the use of digestate and its fractions as fertilizers for agricultural crops are inconsistent. For example, the 2006 study considers digestate an excellent fertilizer applicable without restrictions in agriculture (FITA, 2006). On the contrary, Kolář et al. (2010) claims that the digestate is a weak mineral fertilizer due to the low content of mineral nutrients (nitrogen and potassium) in excess of water. The truth is that during biogas production, depending on the composition of input raw materials, the organic matter is transformed and stabilized and the organic carbon content (C) decreases by 20-95% (Möller 2015). For that reason, we have chosen to focus our research in this direction.

The main objective of our research was to test any positive effects of enriching the digestate with an organic component. In our case, the organic component was represented by haylage, but it can also be replaced by silage. In the experiment, grass mixtures were tested as the main source of an organic matter increase in agricultural land, because after one year, in the case of grass mixtures, up to 80% of the incorporated biomass is decomposed (Černý et al., 1997).

2 METHODOLOGY OF RESEARCH

Field testing took place on one of the private farms in the North Moravian Region (North of the Czech Republic). The test area is located in the climatic region MT7. This region is characterized by short summer periods, which are slightly cold and dry, and mild autumn (Tolasz, 2007). The tests were carried out on a stretch of 2 ha, in places that are regularly used for agricultural purposes. The test area was divided into four sections (each of 0.5 ha). In terms of geomorphology, the tested territory belongs to the Ostrava basin and as regards pedology, it is formed by a mirrored luvisols. The year when the experiment took place was considered very warm (abnormally) and as regards precipitations normal in terms of meteorology.

We were tested three different mixtures of digestate and haylage, by which the standard agricultural areas were fertilized. They were used in weight ratios (sage:digestate) of 3:1, 5:1 and 10:1. The digestate and sage have the following characteristics listed in Table 1.

Table1: Digestate and sage characteristics

Indicator	Unit	Sage	Digestate	Method
humidity	%	32.23	95.67	annealing and subsequent deduction
N - ammoniacal	mg/kg dry matter	1460	32300	photometry
N - total	% dry matter	1.58	7.76	nitrate after distillation
total organic carbon	% dry matter	41.7	39	infrared spectrometry
pH		6.6	7.9	potentiometry
phosphorus	g/kg dry matter	2.22	10.5	photometry
potassium	g/kg dry matter	24.2	30.2	AAS method - flame technology
calcium	g/kg dry matter	5.51	11.3	AAS method - flame technology
magnesium	g/kg dry matter	1.43	9.98	AAS method - flame technology
sodium	g/kg dry matter	0.74	6.12	flame emission spectrometry

The ratios were then compared with standard farming practices (only with the use of standard fertilizers) and with the case of using only digestate as a fertilizer. The haylage was cut to a maximum length of 25 mm because its length directly affects the rate of nutrients release into the soil and was plowed into the soil manually.

The aim of this experiment was to incorporate into the soil, together with digestate, an organic component, which would at least partially offset the organic matter losses (soil organic carbon) so that silage occurs in agricultural practice.

For the research, Zea mays - Figorinio hybrids and basic fertilizers were used: urea and Polidap fertilizers (mineral fertilizer containing phosphorus – 46%, nitrogen – 18% and about 3% of sulfur) and LAV ammonium with limestone which is a nitrogen fertilizer containing 27% of nitrogen). In addition to these standard fertilizers, digestate or prepared mixtures were also added to the determined areas.

The digestate was removed on 27 May 2016, and on the same day the mixtures of digestate and haylage were made and incorporated into the soil.

Figure 1: Putting the individual mixtures into the soil within the examined area

The total research area was 200 m^2 (50 m^2 for each fertilizer variant – 10:1, 5:1, 3:1 and fertilized only with digestate). Depending on the amount of nitrogen expected, 100 l of digestate per 50 m^2 of the test area or 120 kg of the fertilizer mixture (individual ratios of haylage and digestate) were applied to soil on 27 May 2016. In this case, it was based on Goverment Regulation No 262/2012 Coll. (as amended).

3 RESULTS AND DISCUSSION

Soil samples were collected at the start of the experiment (on 15 April 2016) and subsequently taken from the individual areas on 7 September 2016 just prior to harvesting. Basic samplings were made from the ornate layer (25-30 cm) so that five injections were always a mixed sample. The soil analyses were performed in an accredited laboratory on the same day of their collection. The evaluation of selected elements (according to EN ISO 12020 in the case of Al and ČSN 757385 for Fe) and nutrients in the soil and pH according to JPP ÚKZÚZ was carried out and the total dry matter was determined (according to EN 15934 and EN 15935).

The main objective of the work was to determine chemical properties of the soil, namely the soil reaction and the content of selected macroelements and microelements. The total content of selected elements in the soil and their accessible form were determined and compared. In the case of two selected elements – Al and Fe – it can be said that the total content of the elements (and their compounds) in the soil is high, the content of their accessible exchangeable or water-soluble forms is orderly lower, which corresponds to the standard distribution of the elements in the soil.

The highest concentration was shown by an irreversible form of iron and aluminium (17,600-19,000 mg/kg dry matter). The source of the subsidy for these elements is in our opinion the mother rock; we do not expect significant influence of anthropogenic resources on the two elements.

Nitrogen was determined in the form of ammonium ions, nitrate ions and also as total mineral nitrogen. The concentration of $N\text{-}NH_4$ is the lowest, which corresponds to normal pedochemical processes. The total N content in soil is often reported in conjunction with humus content in soil or with oxidizable carbon content (CO_X) as a C:N ratio. According to Sirovy and Facka (1967), the C/N ratio of 15-18 can be considered a sufficient supply of nitrogen. In the case of our experiment, it ranged from 16.5 to 20.7. When the fertilizer was most favourable in the case of fertilization, the ratio of the mixture was 5:1 (C/N = 16.6) and of the digestate fertilizer C/N = 18. The other mixtures already have nitrogen because of the ratio less accessible. Nitrogen is a basic biogenic element necessary for plant growth, and its lack effecting plant health is a serious physiological disorder.

In soils, phosphorus occurs in both inorganic and organic matter, and the most of its content in soils is inaccessible to plants. The concentration of accessible, poorly adsorbed inorganic so-called labile phosphorus (i.e. anionic orthophosphoric acid) in the soil solution is very low and must be regularly supplemented for crops. Most of the phosphorus in soils is in the form of organic compounds (20-80%) and in our experiment its source in the form of inorganic phosphates with Fe and Al (Stevenson, 1986; Brady and Weill, 2002) is also evident. In our experiment, the maximum amount of phosphorus was recorded on 5:1 fertilized surfaces and digestate, the lowest absolute value of accessible phosphorus reaching the reference area. Different values differ by more than 25%. Phosphorus deficiency occurs primarily in the production of fetuses.

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Table 2: Results of analyses of tested soil samples from individual tested areas. In the case of substances marked M III, their accessible form is indicated on the basis of their extract in: nitric acid 65%, ammonium fluoride, ammonium nitrate, concentrated acetic acid and ethylenediaminetetraacetic acid (EDTA).

Indicator	Unit	3:1	5:1	10:1	Digestate only	Reference area	Methodology used
Al	mg/kg dry matter	21400	22100	20400	22700	22500	AAS method – flame technology
Fe	mg/kg dry matter	18100	19000	18200	18100	17600	AAS method – flame technology
total dry matter	%	80.98	83.65	82.91	82.28	80.41	gravimetry
Ph (CaCl2)		5.5	5.4	5.6	5.5	5.7	potentiometry
Ca – M III	mg/kg dry matter	1342	1355	1465	1349	1402	AAS method – flame technology
K – M III	mg/kg dry matter	217	237	184	219	234	flame emission spectrometry method
Mg – M III	mg/kg dry matter	128	124	143	128	150	AAS method – flame technology
P – M III	mg/kg dry matter	78	85	70	85	63	AAS method – flame technology
Fe – M III	mg/kg dry matter	361	371	363	358	345	AAS method – flame technology
Al – M III	mg/kg dry matter	662	651	613	654	648	AAS method – flame technology
Mn – M III	mg/kg dry matter	67	73	76	60	73	AAS method – flame technology
organic carbon	% dry matter	2.7	2.31	2.13	2.52	2.75	photometry
N - ammoniacal	mg/kg dry matter	5.01	5.69	2.83	1.49	3.46	titration
N - nitrate	mg/kg dry matter	4.95	7.26	4.84	4.67	4.59	nitration after distillation
N - mineral	mg/kg dry matter	9.96	13	7.67	6.16	8.05	potentiometry – ISE and the sum of the mineral nitrogen by counting the measured values
N total	% dry matter	0.13	0.14	0.08	0.14	0.14	

The content of accessible (or water soluble) potassium forms depends on the mineralogical and grain composition of the soil sorption complex. In general, finer grained soils and soils with lower pHs show higher amounts of K (Brady and Weil, 2002). The highest total amount of potassium is in the case of a 5:1 ratio fertilized area, which is very close to the reference area, the lowest amount is on the 3:1 and 10:1 fertilized surfaces. Differences in the total amount of available potassium are in the range of 20%. The main role of potassium is to provide a suitable ion environment for metabolic processes (e.g. as a regulator of growth regulation and other growth processes), helps regulate processes in the plant (e.g. opening and closing of vents).

The bulk of calcium is bound in soils by insoluble or poorly soluble compounds (carbonates, silicates, aluminosilicates, etc.). The exchangeable (accessible) form is represented by 1-2% of the non-exchangeable form (Tůma, 2002). The content of exchangeable Ca (especially $Ca(HCO_3)2$) is closely related to the CO_2 content (i.e. biologically active soil). For 10:1 and on the reference surface, the values vary about 10%. Calcium significantly affects the metabolism of plants and their deficiency affects the intake of nutrients.

Magnesium in soils occurs in similar compounds as calcium. The exchangeable or soluble form of Mg is present in the soil solution and its acceptability affects the content of antagonist ions, especially K +, Na + and

Ca + (Tůma 2002). The highest content of accessible Mg was in the case of fertilization with mixtures of 10: 1 and the reference area, in the case of other areas it varied by up to 17%. Magnesium plays an important role in photosynthesis because it forms the central chlorophyll atom; its deficiency is usually manifested as leaf chlorosis.

It is clear from Tab. 1 that the total iron content is almost entirely in the form of inaccessible forms (the proportion of the soluble form is between 1.6-2% of the total iron content in the soil). Differences in the content of accessible iron forms in the fertilizer chosen are not significant, the fertilized areas showed higher concentrations of accessible Fe than the reference area, but the ratio between its accessible and inaccessible form was almost the same, only a 5:1 ratio was less than 1.6% of the total iron content.

Plants are able to accept manganese only as Mn^{2+} or as chelate in exchange or water-soluble form. Its accessibility is related to the pH and the size of soil particles – it is better absorbed in more acidic, finer soils. The set values were 22% at their minimum and maximum. The highest value was the 10:1 fertilized area, followed by the 5:1 fertilized areas and the reference area. In plants, manganese is an important component of oxygen-forming complex that decomposes water in chloroplasts, which takes place in the primary phase of photosynthesis. Its deficiency damages chloroplasts and is the cause of chlorosis.

Like iron, aluminum is mainly contained in a bound, non-replaceable form and its total soil concentration is high in the content of accessible aluminum significantly lower. Accessible aluminum was found at the lowest concentrations in the 10:1 mixed area, where it differed by 7.5% from the other areas. The second lowest aluminum concentration was determined on the reference surface. The aluminum ion (Al^{3+}) is the most toxic form for plants which acts on apical root zones and stops root growth in a very short time.

4 CONCLUSION

The main objective of the experiment was to test the possibility of improving the properties of digestate by enriching it with an organic ingredient in the form of sage. In terms of the results of our experiment, we can state that the distribution of elements in the soil with the fertilizer mixtures of digestate and haylage proved to be good because the soil sampled on individual test surfaces showed higher concentrations of accessible forms of selected micro- and macro-nutrients. In case of the mixtures, higher levels of accessible nutrients were recorded in most cases than in the areas that were fertilized only with the digestate. In a view of the increase in the amount of accessible nutrients, a 5:1 weight ratio (digestate:haylage) was found to be suitable, showing the maximum amount of nitrogen, phosphorus, potassium and iron in all tested mixtures compared to the digestate and the reference surface. Thus, the soils provide plants as much as possible with the essential elements for the growth and development of fruits and the regulation of metabolic processes. Unfortunately, this mixture also exhibited the highest amount of total aluminum and, depending on it, the highest amount of accessible aluminum that may adversely affect root growth. The highest magnesium and manganese content was shown by the 10:1 fertilizer mixture (digestate:haylage) which also exhibited the lowest amount of aluminum (and also accessible aluminum). The soils fertilized with this mixture thus supported mainly photosynthesis in plants (magnesium forms, the central chlorophyll atom, and manganese supports primarily the primary phase of photosynthesis).

The main limiting condition of this test is the high dependence on external factors that we were unable to influence – especially climatic and soil conditions, and it would be advisable to carry out an analysis of the test plants to determine the quantity and distribution of the elements in their individual parts. Since the purpose of creating the mixtures was primarily to increase organic soil, it would be appropriate to continue this experiment cyclically over a longer period of time (optimally five years) to better map out whether it is a real improvement in the properties of agricultural land or not.

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