Agronomy Research **19**(4), 1929–1937, 2021
https://doi.org/10.15159/AR.21.125

Digestate application with regard to greenhouse gases and physical soil properties

P. Šařec[1], J. Korba[1,*], V. Novák[1] and K. Křížová[1,2]

[1]Czech University of Life Sciences Prague, Faculty of Engineering, Department of Machinery Utilization, Kamýcká 129, CZ165 00 Prague 6, Czech Republic
[2]Crop Research Institute, Division of Crop Protection and Plant Health, Drnovská 507/73, CZ161 06 Prague, Czech Republic
[*]Correspondence: korba@tf.czu.cz

Received: February 1st, 2021; Accepted: June 18th, 2021; Published: August 18th, 2021

Abstract. The article deals with the method of application of digestate with regard to the environment, soil properties and utilization of nutrients by plants. The aim is to monitor the dependence of the emission gas leakage and the dose of applied fertilizer. With the current expansion of biogas plants, a large amount of waste product, especially digestate, is being generated. This product is most often used as a liquid organic fertilizer because it contains substances important for plant growth. The disadvantage of this fertilizer is the release of greenhouse gases into the air. The digestate contains mainly ammonia, nitrogen in the residual organic matter and is a fertilizer with rapidly releasing nitrogen. The ammonium nitrogen contained in the digestate is easily subject to air losses. Therefore, a method of application for a certain crop is sought, where the smallest leaks of gases into the air occur. Different amounts of doses for the same route of administration are compared. To measure the amount of emission gases, a wind tunnel was placed on each variant of the application, taking air above the soil surface, which is discharged to the gas analyser. The monitored greenhouse gases are CH_4, NH_3 and CO_2. Furthermore, physical properties of soil were monitored in order to verify the conditions of the experiment. One of the parameters measured was the soil bulk density of the soil by taking intact soil samples. The penetration resistance of the soil was also determined, which indicates the degree of compaction. The use of nutrients was assessed through the condition of the stand on each variant by monitoring vegetation indices using remote sensing of the earth.

Key words: digestate, greenhouse gases, remote sensing, physical soil properties, ammonia.

INTRODUCTION

In today's age of intensive agriculture, we can grow enough food on a smaller area of agricultural land than before, but the soil must be supplied with fertilizers in order to provide enough nutrients. On the area remaining, we can grow plants for other uses. One of such uses relates to biogas plants, where some surplus of agricultural crops can be processed, alongside with the waste generated during livestock and food production. Previously, the input biomass originated from lower quality agricultural crops and plant wastes. Today, when a large amount of input biomass is needed, there is a targeted cultivation of agricultural crops most suitable for biogas production (Černá et al., 2016; Mazur et al., 2020).

Biogas is formed during anaerobic digestion of organic matter in a fermentation tank. The resulting gas contains methane, carbon dioxide and other gases. After the removal of unwanted gases from the biogas, the gas is burned in a cogeneration unit, which produces electricity using a generator (CZ Biom, 2010). The by-product is then a heat, which is partially used in the fermenter to keep it in ideal conditions. Methane is particularly suitable for energy use. This method of electricity generation is currently supported because biomass is a renewable resource (Bloch-Michalik & Gaworski, 2015). Biogas production produces a large amount of digestate, which is a waste product of anaerobic digestion. This product is usually used as a liquid organic fertilizer because it contains a certain amount of nutrients and organic substances (Massaccesi et al., 2013). Less often, the digestate separates into a liquid component and a dry matter (Černá et al., 2016). The digestate is produced in the biogas plant continuously throughout the year. The biogas plant will generate about two tons of digestate per megawatt hour of electricity produced. The exact amount depends on the composition of the input biomass and the process conditions in the fermenter (Ditl et al., 2017). Due to the agronomic deadlines for application, it must be stored for up to several months. The disadvantage of this fertilizer is the release of emissions into the air (Holm-Nielsen et al., 2009). The digestate contains mainly ammonia, nitrogen in the residual organic matter and is a fertilizer with rapidly releasing nitrogen. The ammonium nitrogen contained in the digestate is easily subject to air losses. Agriculture is a major polluter of the air with this gas. The monitored gases are among the greenhouse gases that currently negatively affect the global warming of the planet. Agriculture is one of the biggest air pollutants of this gas. Methods for measuring ammonia emissions in animal production are well developed, but methods for measuring this gas after application are not uniform (Šimek & Cooper, 2002; Dietrich et al., 2020). The concentration of ammonia, nitrous oxide, methane and carbon dioxide in the air above the soil surface is high after application but decreases over time (Češpiva & Zabloudilová, 2016; Dietrich et al., 2020), therefore the measurement should be performed as soon as possible after application.

The aim is to measure the amount of emissions produced after application and incorporation into the soil depending on the dose of digestate, because it is important to optimize the amount of organic fertilizer to minimize the amount of greenhouse gases emitted. When looking for the optimal dose, we must not forget to supply enough nutrients to the plants. Another goal is to compare the physical properties of the soil for different doses of application.

MATERIAL AND METHODS

On the experimental plot on 27th August 2020, digestate was applied by a tank with a disc application unit after the pre-crop had been harvested. Cattle slurry, corn silage and grass silage were used as raw input materials in the biogas plant. The experimental plot was located near the locality Čechtice in the Central Bohemian Region, Czech Republic (GPS 49° 37'07"N 15° 04'04" E). According to USDA, soil texture of the field was sandy loam. Each variant had a width of 24 m, and a length of 100 m. Samples of below mentioned variables were taken in a rectangular grid corresponding to the respective numbers of samples per variant. The digestate was applied by a disk application unit at different rates on four variants, with the fifth variant as control without digestate application, but with the same soil tillage treatment. The depth of digestate incorporation into soil reached approximately 10 cm. The respective digestate rates were 10, 20, 30, 40 t ha^{-1}. The maximum dose of 40 t ha^{-1} was chosen because this dose contains approximately the maximum recommended amount of nitrogen per a single dose. The measurement of emissions and physical properties of soil followed immediately after the digestate application. The monitored emission gasses were CO_2, CH_4 and NH_3.

An INOVA 1412 gas analyser was used to measure the emissions of the gases. Due to the dimensions of the instrument and the battery, the device was located in a transport vehicle. From the wind tunnels (Fig. 1) located at the monitored places, special Teflon hoses lead, through which the analysed air was supplied. In the analyser, a sample of air in a chamber is exposed to UV rays of a given frequency. There is a resonance of the molecules of the monitored gas and subsequent transformation into an oscillating motion of the molecules. No resonance occurs with the other components of the sample. The oscillating motion of the particles is detected by sensitive sensors. Wind tunnels consist of a plastic block that does not have a 35 × 50 cm wall on the underside (Loubet et al. 1999, Yang et al., 2018). The wind tunnel has two ventilation openings on the opposite sides. One opening is equipped with a fan with the possibility of speed control, which ensures the exact speed of air flow out of the wind tunnel, see Fig. 1. The other opening acts as air intake, where the air flow rate is measured and recorded by an anemometer. Inside, there is a thermometer that continuously monitors and records the temperature at which the measurement takes place. When using the INNOVA 1309 option, gas measurements can be performed simultaneously on up to five variants. After an hour, the wind tunnels were moved to another location within the variant, monitoring took place for over approximately three hours. All measured data were recorded and then transferred to a PC.

Figure 1. Emissions measuring wind tunnel.

Simultaneously with the above mentioned measurement, undisturbed soil samples were taken in order to determine soil bulk density by means of Kopecky cylinders ($V = 100$ cm^3). Soil samples were taken at a depth of 5 to 10 cm. Five samples were taken for each variant. The measurement served as informative on the homogeneity of the field.

Utilizing a penetrometer, another parameter concurrently monitored was the penetration resistance. This method is indirect, because the soil resistance depends not only on the porosity and bulk density but also on soil texture and moisture. It is advisable to compare the measured results only within one plot or with plots of similar properties. This measurement can detect excessive soil compaction. Penetration resistance was evaluated at the depths of 4, 8, 12, 16 and 20 cm in ten samples per variant.

Satellite data of Sentinel-2 (European Space Agency; ESA) was used for crop status evaluation. Five cloud-less images were selected and processed to gather 20–24 pixels (resolution 10 m/px) for each variant. Besides the commonly used Normalized Difference Vegetation Index (NDVI), Green Normalized Difference Vegetation Index (GNDVI) was derived. GNDVI is trusted to be suitable to evaluate plant nitrogen content and is also more sensitive to chlorophyll concentration than NDVI. With regard to the sparse vegetation cover, Soil Adjusted Vegetation Index (SAVI) was also calculated. This spectral index was designed to suppress the influence of pixels representing soil. The correction factor for SAVI equation was set to 0.5. Equations for all three used indices are provided in Table 1. The data was processed using open-source software ESA SNAP, QGIS and R. Yields can be predicted by long-term monitoring of crop stands using remote sensing (Tunca et al., 2018).

Table 1. Vegetation Indices emloyed

Index	Abbreviation	Formula	Authors
Green Normalized Difference Index	GNDVI	$\frac{NIR - GREEN}{NIR + GREEN}$	(Gitelson et al., 1996)
Normalized Difference Vegetation Index	NDVI	$\frac{NIR - RED}{NIR + RED}$	(Rouse et al., 1974)
Soil Adjusted Vegetation Index	SAVI	$\frac{(1 + L) \cdot (NIR - RED)}{(NIR + RED + L)}$	(Huete, 1988)

Statistical analysis of data was performed using the Statistica 12 software. The ANOVA test was employed to evaluate gas emissions and remote sensing. The paired Wilcoxon test was used to evaluate penetration resistance.

RESULTS AND DISCUSSION

In Table 2, average temperature and humidity values within wind tunnels are presented for the individual plots where the measurement took place. Under similar conditions, the physical properties of the soil were measured. The weather was sunny with with the breeze. The average speed of air flow through the opening in the wind tunnels was set to 0.9 m s^{-1}.

Table 2. Average air temperature (°C) and relative humidity for the field near Čechtice during the measurement for individual trial plots

Dose variant (t ha^{-1})	40	30	20	10	0
Average temperature (°C)	24.29	24.92	26.41	27.55	27.75
Relative humidity (%)	58.74	60.52	45.14	40.82	40.01

Fig. 2 shows the ammonia emission balanced values of the individual variants. At the same time, these values are small up to the edge of measurability. Negatively displayed values are the consequence of the measurability limit of the measuring instrument. These small emission concentrations can be attributed to the method of application. The disc applicator mixes the digestate into the entire treated soil layer, leaving a minimal amount on the soil surface, which is subject to a rapid release into the air. Therefore, the measured NH3 concentration is significantly lower than (Wolf et al., 2014), where the digestate was incorporated in a slightly different way. The measured values show approximately slightly decreasing emissions during the measurement period, which is confirmed by other works (Dietrich et al., 2020; Rosace et al., 2020).

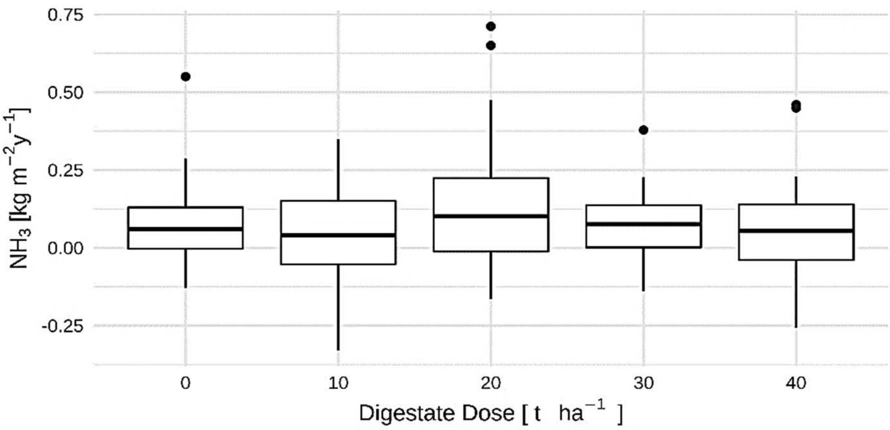

Figure 2. Ammonia emission (kg m^{-2} y^{-1}) for individual digestate dose (t ha^{-1}).

The measured values for methane (Fig. 3) are similarly balanced as for ammonia emissions without statistically significant differences. The same reasons for balanced results apply for methane as for ammonia. When comparing the same time from application, the measured emissions of all application variants are higher than those found by Czubaszek & Wysocka-Czubaszek (2018).

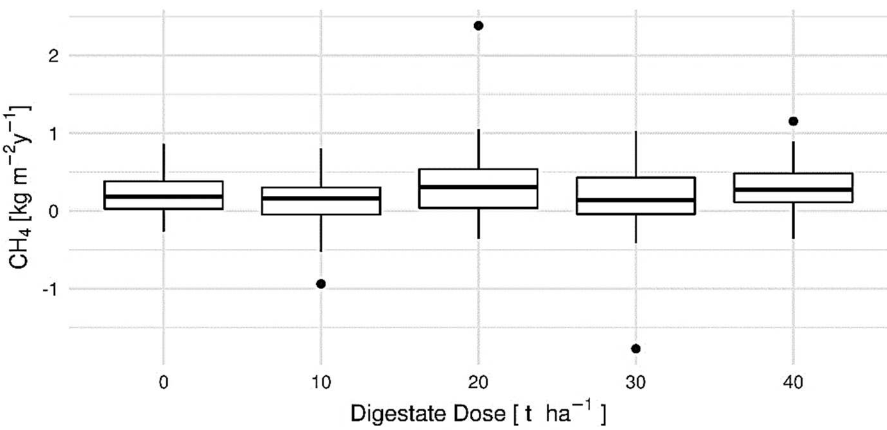

Figure 3. Methane emission (kg m^{-2} y^{-1}) for individual digestate dose (t ha^{-1}).

Differences can be seen in the measurement of carbon dioxide emissions (see Fig. 4), although the measured values have a higher variance. Statistically significant differences were discovered between the 10 t ha^{-1} dose and the control variant without application, then between doses of 10 t ha^{-1} and 30 t ha^{-1}, and finally between doses of 40 t ha^{-1} and 30 t ha^{-1}. The differences were not statistically significant among the other variants. The measured values in all variants were higher than in Rosace et al. (2020), this difference may be due to a different measurement method, although the course of emission leakage over time is similar. When comparing the results of Czubaszek &

Wysocka-Czubaszek (2018) immediately after application, our measured results were smaller, but when compared with their measured results the day after application, our emissions were greater.

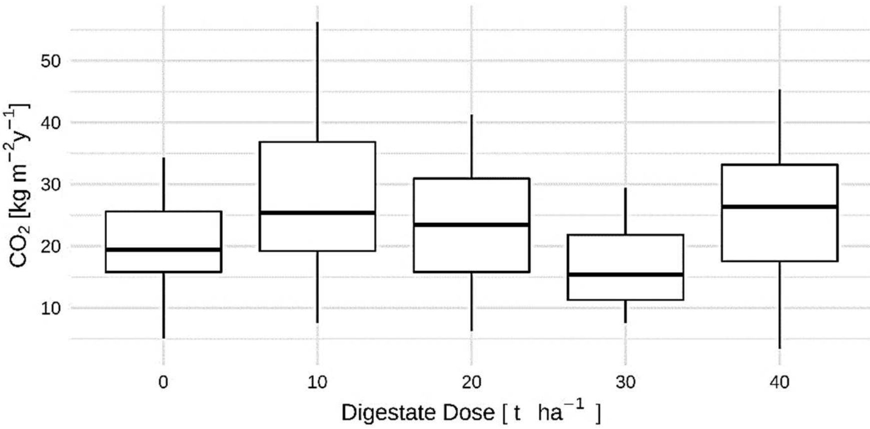

Figure 4. Carbon dioxin emission (kg m^{-2} y^{-1}) for individual digestate dose (t ha^{-1}).

The measurements of the penetration resistance (Fig. 5) in the upper part of the soil, in particular at 4 and 8 cm, can be influenced by the tillage after application of the digestate. At a depth of 12 cm, there are obvious differences, but even here it could be affected by soil tillage. The differences in penetration resistance were then evident in the depth of 16 cm, where the penetration resistances within the variants with a dose of 10 and 20 t ha^{-1} were lower than in the other variants. With smaller differences, a situation like the previous measurement depth can be seen at a depth of 20 cm. Similar resistance values at depths of 16 and 20 cm, which were comparable, were achieved by Beni et al. (2012). Depths of 4–12 cm cannot be exactly compared, because this layer of soil was tilled when applying the fertilizer by the disk application unit.

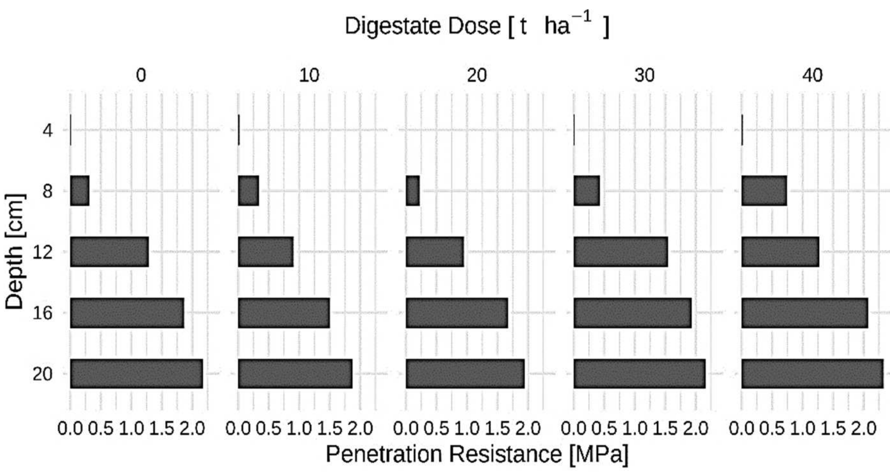

Figure 5. Penetration resistance (MPa) at selected depths.

Fig. 6 shows the highest measured average bulk density value for the variant with a dose of 40 t ha^{-1}. On the contrary, in the variant with a dose of 30 t ha^{-1}, the soil bulk density was the smallest. According to Pokorný et al. (2007), the measured values were below the limit of excessive compaction for a given type of soil. When compared with their first year of measurement, similar values of soil bulk density were reached after application of similar doses of digestate Jaša et al. (2019).

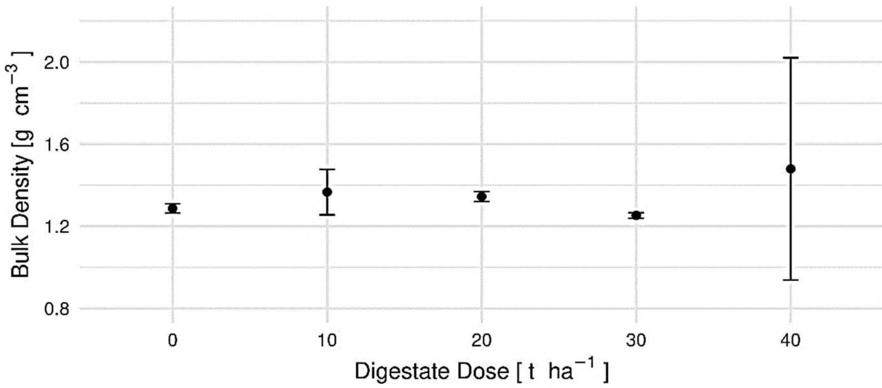

Figure 6. Soil bulk density (g cm^{-3}) for individual digestate doses (t ha^{-1}).

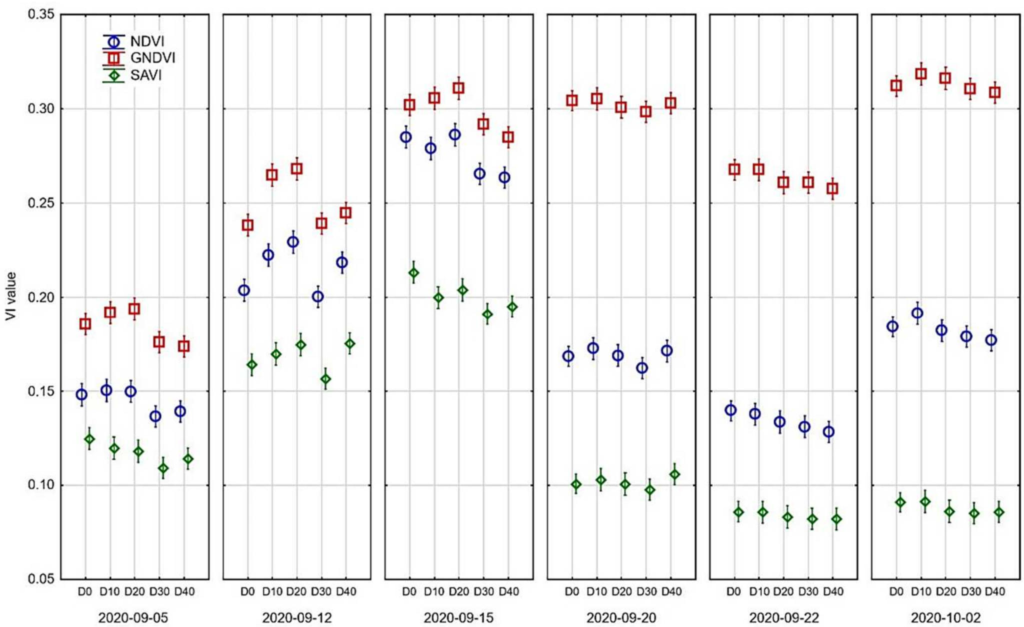

Figure 7. Vegetation indices of individual variants (digestate doses) in the experimental field near Čechtice.

Fig. 7 shows the growth of the intermediate crop after the application of digestate, thus increasing the values of vegetation indices. The differences between the variants were already apparent during the first shooting. Apart from the SAVI index, which decreases approximately with dose, the highest values were reached at a dose of 20 t ha^{-1} but did not differ statistically from the control variant and the dose of 10 t ha^{-1}. The results can only be affected by growing vegetation. A similar result can be seen in the next evaluated date, where the highest vegetation indices were attained by the dose of 20 t ha^{-1}, but statistically the result did not differ from dose 10 and 40 t ha^{-1}. On the third monitored date, the SAVI index reached the highest value in the control variant but did not differ statistically with the dose variants of 10 and 20 t ha^{-1}. For the other two indices, except for the dose of 40 t ha^{-1}, the statistical analysis did not find any differences. On the fourth control date, the indices were balanced. The GNDVI index reached its maximum for the variant of 10 t ha^{-1}, but without significant differences compared to the others. The NDVI index reached the highest value at 10 t ha^{-1}, but except for the variant 30 t ha^{-1} without any statistical difference. The SAVI index reached the highest value at 40 t ha^{-1} but except for the variant 30 t ha^{-1} without any significant difference. On the fifth date of observation, in addition to the SAVI index, there were differences among the groups of variants. The control variant worked best. The last evaluated date presented the best variant with dose as of 10 t ha^{-1}, but except for the variant with dose 40 t ha^{-1} without any significant difference. In this case, the growth was not yet sufficient for the growth phase to make an accurate estimate.

CONCLUSION

Measurements of emissions after digestate incorporation showed differences among variants only in CO_2 concentrations. The concentrations of other monitored gases were discovered without any significant differences. After application, lower values of penetration resistance at depths of 16 and 20 cm were measured for variants with a dose of 10 and 20 t ha^{-1} than for the other doses. Concerning soil bulk density, no significant differences were found. Remote sensing of the stand showed only small differences among vegetation indices of individual variants. Generally low measured levels of emissions from the soil surface were probably caused by the digestate having been incorporated into the soil. Therefore, this method of application can be recommended.

ACKNOWLEDGEMENTS. Supported by the Technology Agency of the Czech Republic, by the project TAČR TH04030132, and by the Czech University of Life Sciences, Faculty of Engineering in the frame of the internal project IGA 2021:31180/1312/3102. This research was also funded by the Ministry of Agriculture of the Czech Republic under grant number RO0418.

REFERENCES

Beni, C., Servadio, P., Marconi, S., Neri, U., Aromolo, R. & Diana, G. 2012. Anaerobic digestate administration: Effect on soil physical and mechanical behavior. *Communications in Soil Science and Plant Analysis* **43**(5), 821–834.

Bloch-Michalik, M. & Gaworski, M. 2015. A proposition of management of the waste from biogas plant cooperating with wastewater treatment. *Agronomy Research* **13**(2), 455–463.

CZ Biom (2010) Guide to the production and use of biogas. Prague, Czech Republic: CZ Biom – České sdružení pro biomasu [online] (in Czech).

Czubaszek, R. & Wysocka-Czubaszek, A. 2018. Emissions of carbon dioxide and methane from fields fertilized with digestate from an agricultural biogas plant. *International Agrophysics* **32**(1), 29–37.

Černá, I., Pecen, J., Ivanova, T. & Piksa, Z. 2016. The dependence of the durability of digestate briquettes and sorption properties on represented particle sizes. *Agronomy Research* **14**(5), 1548–1561.

Češpiva, M. & Zabloudilová, P. 2016. Methods for determination of ammonia emissions from soil. *AgritechScience* [online]

Dietrich, m., Fongen, m. & Foereid, B. 2020. Greenhouse gas emissions from digestate in soil. International *Journal of Recycling of Organic Waste in Agriculture* **9**(1), 1–19. doi:10.30486/IJROWA.2020.1885341.1005

Ditl, P., Nápravník, J. & Šulc, R. 2017. Chemical pre-treatment of fugate from biogas stations. *Biomass and Bioenergy* **96**, 180–182.

Gitelson, A.A., Kaufman, Y.J. & Merzlyak, M.N. 1996. Use of a green channel in remote sensing of global vegetation from EOS- MODIS. *Remote Sensing of Environment* **58**(3), 289–298.

Holm-Nielsen, J.B., Al Seadi, T., Oleskowicz-Popiel, P. 2009) The future of anaerobic digestion and biogas utilization. *Bioresour Technol.* **100**(22), 5478–5484.

Huete, A.R. 1988. A Soil Adjusted Vegetation Index (SAVI). *Remote Sensing of Environment* **25**, 295–309.

Jaša, S., Badalíková, B. & Červinka, J. 2019. Influence of digestate on physical properties of soil in ZD budišov. *Acta Universitatis Agriculturae Et Silviculturae Mendelianae Brunensis* **67**(1), 75–83.

Loubet, B., Cellier, P., Génermont, S. & Flura, D. 1999. An evaluation of the wind-tunnel technique for estimating ammonia volatilization from land: Part 2. influence of the tunnel on transfer processes. *Journal of Agricultural and Engineering Research* **72**(1), 83–92.

Massaccesi, L., Sordi, A., Micale, C., Cucina, m., Zadra, C., Di Maria, F. & Gigliotti, G. 2013. Chemical characterisation of percolate and digestate during the hybrid solid anaerobic digestion batch process. *Process Biochemistry* **48**(9), 1361–1367.

Mazur, V.A., Pantsyreva, H.V., Mazur, K.V., Myalkovsky, R.O. & Alekseev, O.O. 2020. Agroecological prospects of using corn hybrids for biogas production. *Agronomy Research* **18**(1), 177–182.

Pokorný, E., Šarapatka, B., Hejátková, K. 2007. Evaluation of soil quality in an ecological farm: a methodological aid. Náměšť nad Oslavou: *ZERA - Zemědělská a ekologická regionální agentura* (in Czech).

Rosace, m.C., Veronesi, F., Briggs, S., Cardenas, L.M. & Jeffery, S. 2020. Legacy effects override soil properties for CO2 and N2O but not CH4 emissions following digestate application to soil. *GCB Bioenergy* **12**(6), 445–457.

Rouse, J.W., Jr., Haas, R.H., Schell, J.A. & Deering, D.W. 1974. Monitoring vegetation systems in the Great Plains with ERTS. NASA. Goddard Space Flight Center 3d ERTS-1 Symp., Vol. **1**, Sect. A

Šimek, M. & Cooper. J.E. 2002. The influence of soil pH on denitrification: Progress towards the understanding of this interaction over the last 50 Years. *Eur. J. Soil Sci.* **53**, 345–54.

Tunca, E., Köksal, E.S., Çetin, S., Ekiz, N.M. & Balde, H. 2018. Yield and leaf area index estimations for sunflower plants using unmanned aerial vehicle images. *Environmental Monitoring and Assessment* **190**(11). doi:10.1007/s10661-018-7064-x

Wolf, U., Fuß, R., Höppner, F. & Flessa, H. 2014. Contribution of N2O and NH3 to total greenhouse gas emission from fertilization: Results from a sandy soil fertilized with nitrate and biogas digestate with and without nitrification inhibitor. *Nutrient Cycling in Agroecosystems* 1**00**(1), 121–134.

Yang, J., Jiao, Y., Yang, W.Z., Gu, P., Bai, S.G. & Liu, L.J. 2018. Review of methods for determination of ammonia volatilization in farmland. Paper presented at the *IOP Conference Series: Earth and Environmental Science* **113**, 012022.