doi: 10.17221/530/2015-PSE

The effect of digestate, cattle slurry and mineral fertilization on the winter wheat yield and soil quality parameters

T. Šimon, E. Kunzová, M. Friedlová

Crop Research Institute, Prague-Ruzyně, Czech Republic

ABSTRACT

This study compares the effect of application of digestate, straw, cattle slurry and inorganic fertilizers on crop yield and soil organic matter content. Total organic carbon (C), total organic nitrogen (N), hot water soluble C, microbial biomass C and hydrophobic soil components were evaluated in soil from the field experiment in Prague-Ruzyně (Orthic Luvisol, clay loam) with winter wheat. All fertilized treatments significantly increased grain yield above the level of non-fertilized control (5.68 t/ha), and the sequence was as follows: digestate (9.88 t/ha) > NPK (9.80 t/ha) > cattle slurry (9.73 t/ha) > digestate + straw (9.35 t/ha). Average organic C content in the soil ranged from 1.668–1.704% and the effect of different fertilization was not significant. The highest increase of microbial biomass C was recorded in digestate + straw (43.2% increase compared to control). Highly significant correlations were found between hydrophobic soil components and hot water soluble C ($r = 0.988$; $P \geq 0.05$) and microbial biomass C ($r = 0.964$; $P \geq 0.05$). Total organic N content ranged from 0.157–0.160% and differences among treatments were insignificant. Fertilization with digestate itself brings an effect in increasing crop yield, but does not improve the level of soil organic matter significantly.

Keywords: digestion; energy crops; *Triticum aestivum*; macronutrients; animal slurry

The anaerobic digestion of biomass such as energy crops, organic residues and animal wastes for biogas production is considered as one of the most efficient ways of renewable energy production (Vaneeckhaute et al. 2013). Subsidy policy through the EU funds contributes to a rapid development of biogas plants in Europe. In the Czech Republic, rather massive development in the implementation of biogas stations has been recorded in the last three years. Along with the growing number of biogas stations, whose number is currently around 550, there is an increasing production of digestate as a by-product of the biogas production. Liquid digestates (fugates) contain more mineral nitrogen (usually 5–6% in dry weight) and less organic carbon than the non-digested input materials (Johansen et al. 2013), and C/N ratio in digestate can be ten times lower than that of farmyard manure (Alburquerque et al. 2012). Digestates also have higher ammonium:total nitrogen ratios, decreased organic matter contents, elevated pH values, and reduced viscosities compared to undigested animal manures (Möller and Müller 2012). Due to the increasing use of digestate as a substitute for farmyard manure in practice it is necessary to monitor the effect of the digestate on soil, its quality and fertility. Recently, studies on the fertilizing effects of different types of digestate have been performed (Tambone et al. 2010) as well as short-term incubation experiments comparing the effect of digestate additions and other organic and mineral fertilizers on microbial communities in soil, organic C and N, CO_2 and N_2O emissions (Johansen et al. 2013), nutrient content in the soil, microbial biomass and mineralization (Galvez et al. 2012). Longer-term monitoring of the impact of digestate on crop yield and soil properties in field conditions and comparison with different other fertilizers is still missing, due to the short period of massive application of digestate in agriculture.

Supported by the Ministry of Agriculture of the Czech Republic, Projects No. QJ1210211 and RO0415.

doi: 10.17221/530/2015-PSE

However, studies published so far have shown that digestate can be a good source of quickly available nitrogen and other macro- and micronutrients for plants and can partly replace cattle slurry application or mineral fertilization (Garfí et al. 2011, Alburquerque et al. 2012, Šimon and Kunzová 2013). On the other hand, less organic C is available for growth and activity of the soil microbial community and the soil organic matter stock can gradually deplete with time (Arthurson 2009). When applying digestate, it is therefore appropriate to simultaneously deliver soil organic matter from other sources, mainly by incorporating crop residues and straw. In the present study, the liquid digestate used as a fertilizer for winter wheat under field conditions was evaluated over a three-year period and the effect on crop production and soil properties (regarding the quantity and quality of soil organic matter) was compared with those of a mineral fertilizer and traditional cattle slurry.

MATERIAL AND METHODS

The study site was located in Prague-Ruzyně, Czech Republic (50°05'15''N, 14°17'28''E). Altitude of the site is 370 m a.s.l., average annual temperature is 8.2°C and the average annual precipitations are 450 mm. The taxonomical soil unit is Orthic Luvisol, clay loam, developed on diluvial sediments mixed with loess (clay content = 27%, pH_{KCl} = 7.0). The experiment has been running since 2012 and it was established in a randomized design with five fertilization treatments: Control – without organic or mineral fertilization; Dig – digestate; Dig + St – digestate + straw; NPK – mineral fertilization; CSl – cattle slurry. Main characteristics of the digestate and cattle slurry used in the experiment are given in Table 1. The plot size was 3 m × 10 m (30 m^2). Each of the five treatments had four replicates. Annual doses and nitrogen input by organic and mineral fertilizers applied are shown in Table 2. 30 kg P and 90 kg K was applied per ha annually in mineral and/or organic form. Digestate and cattle slurry were applied to the soil surface with hose applicator and immediately ploughed followed by presowing soil preparation and sowing. Winter wheat (cv. Mulan) was cultivated in 2012–2014; the seed rate was 180 kg/ha and the dates of sowing were September 26, 2012 and September 30, 2013. Grain and straw were harvested in July both in 2013 and 2014 and yield from individual plots was recalculated for t/ha at 85% dry matter. In the period 2013 to 2015, soil sampling was carried out from topsoil in the depths of 0–0.2 m at four sites of each individual plot before mineral fertilization at the beginning of April.

C fractions and total N. Microbial biomass C (C_{mic}) was determined by the chloroform fumigation-extraction method (Vance et al. 1987). Hot water soluble C (C_{hwl}) content in the soil samples was determined according to Schulz (1997). Total organic C (C_{tot}) and total organic N (N_{tot}) were determined on a Vario Max analyser (Elementar Analysensysteme GmbH, Hanau, Germany) in air-dried soil samples. The FTIR spectra were measured on the Thermo Nicolet Avatar 320 FTIR spectrometer, equipped by a Smart Diffuse Reflectance Accessory (Nicolet, Madison, USA) in a homogenous mixture of bulk soil with KBr (FTIR grade, Aldrich, Germany) (Šimon 2007). The FTIR spectra were analysed at absorption bands that indicate the hydrophobic (CH-groups) functional groups. For hydrophobic methyl and methylene groups the CH bands occurred at 3000–2800/cm (Ellerbrock et al. 2005). The area of absorption bands of hydrophobic groups in the FTIR spectra was integrated with spectrometer software (Omnic, version 6a, Nicolet, USA) and was defined as intensities.

Statistics. The basic statistical values i.e. averages, standard deviations (SD) and Pearsons's

Table 1. Main characteristics of digestate and cattle slurry used in the field experiment

Parameter	Unit	Digestate	Cattle slurry
pH		8.65	8.22
Dry matter (DM)	(%)	6.2	7.0
Total N	(% DM)	6.10	4.80
N_{org}		2.44	2.26
N_{min}		3.66	2.54
P		1.03	0.78
K		6.70	3.91
Ca		3.08	2.20
Mg		0.83	0.85
Na		0.50	0.52

doi: 10.17221/530/2015-PSE

Table 2. Average annual doses of organic matter and nitrogen input by organic and mineral fertilizers in the plots of the field experiment

Treatment	Fertilizer (in fresh matter) (t/ha)	Organic nitrogen	Mineral nitrogen	Total nitrogen
		(kg/ha)		
Control	–	–	–	–
Dig	20	30.3	45.3	75.6
Dig + St	20 + 2.5	30.3 + 16.1	45.3	91.7
NPK	–	–	120	120
CSl	30	47.5	53.3	100.8

Control – without organic or mineral fertilization; Dig – digestate; Dig + St – digestate + straw; NPK – mineral fertilization; CSl – cattle slurry

correlation coefficients (*r*) were calculated using Microsoft Excel (Microsoft Corporation, Redmund, USA) and Statistica CZ 12.0 (StatSoft. Inc., Tulsa, USA) software. Data for each year were analysed by an analysis of variance. Tukey's *HSD* test was used to determine significance of differences among individual treatments. The data followed by the same letter do not differ significantly ($P \geq 0.05$).

RESULTS AND DISCUSSION

Crop yield. Average values of winter wheat grain and straw yields in the fertilization treatments are shown in Figure 1. All fertilized treatments significantly increased grain and straw yield compared to non-fertilized control. The increase of grain yield ranged from 39.6–47.4% and the sequence was as follows: digestate > NPK > cattle slurry > digestate + straw. Similarly, Makádi et al. (2012) confirmed that due to the high available nutrients content, digestate application resulted in significantly higher aboveground biomass yields in the case of winter and spring wheat than the farmyard manure and undigested slurry treatment. Field experiments with the application of equivalent amounts of total N indicate that the uptake of N from liquid digested animal slurry equaled that of undigested slurry after surface application, despite the higher NH_4^+-N content of the digestate (Möller et al. 2008). On the contrary, the application of straw together with digestate increased C/N ratio and partially slowed down mineralization and utilization of nitrogen contained in the digestate by plants. Vegetation pot and field trials with vegetables show that the digestate application resulted in comparable or better yields in comparison to mineral fertilizers for kohlrabi (Lošák et al. 2011), tomatoes and green peppers (Kouřimská et al. 2012) and summer watermelon (Alburquerque et al. 2012). Garfí et al. (2011) in a field trial experiment documented that the digestate is an appropriate substitute of manure pre-compost for potato fertilization.

Soil characteristics. Average C_{tot} content in the soil ranged from 1.668–1.704% and the effect of different fertilization was not significant (Table 3). Application of digestate increased C_{tot} content by 2% above the level of non-fertilized treatment. It is well documented that positive changes in the organic carbon content in the soil become evident after long-term application of organic fertilizers

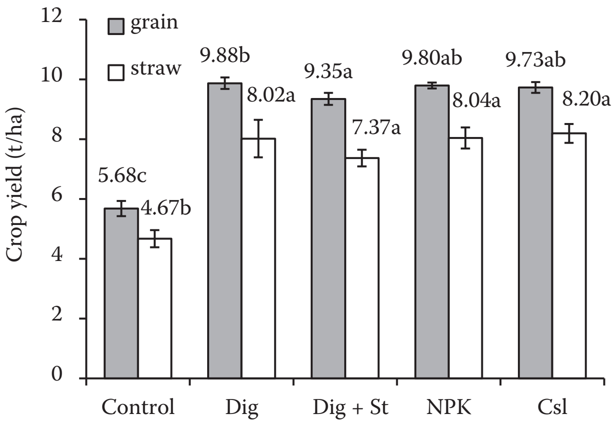

Figure 1. Average winter wheat yield in plots under different fertilization treatments. (experimental site: Prague-Ruzyně). Columns with the same letter do not differ significantly ($P < 0.05$). Bars – standard deviation. Control – without organic or mineral fertilization; Dig – digestate; Dig + St – digestate + straw; NPK – mineral fertilization; CSl – cattle slurry

doi: 10.17221/530/2015-PSE

Table 3. Average content of carbon (C) fractions in soil samples from plots under different fertilization treatments (experimental site: Prague-Ruzyně)

Treatment	C_{tot} (%)	C_{hwl} (μg C/g)	C_{mic} (μg C/g)	C_{mic}/C_{tot}
Control	1.671 ± 0.014	342.0 ± 9	126.7 ± 27.9	0.760 ± 0.173
Dig	1.704 ± 0.001	352.0 ± 23	149.2 ± 72.4	0.875 ± 0.424
Dig + St	1.694 ± 0.047	369.0 ± 20	181.5 ± 65.4	1.061 ± 0.357
NPK	1.691 ± 0.015	344.0 ± 17	150.9 ± 52.5	0.890 ± 0.302
CSl	1.668 ± 0.005	346.0 ± 1	142.2 ± 40.6	0.852 ± 0.241

Control – without organic or mineral fertilization; Dig – digestate; Dig + St – digestate + straw; NPK – mineral fertilization; CSl – cattle slurry; C_{tot} – total organic C; C_{hwl} – Hot water soluble C; C_{mic} – microbial biomass C

(Kubát and Lipavský 2006, Merbach and Schulz 2013). However, the change in the source of organic fertilization may induce changes in the content of soil organic matter (SOM). Such starting changes can be documented by monitoring the content of easily decomposable carbon in the soil in the form of C_{hwl}. This SOM fraction accounts for about 2–3% of the C_{tot} and is assumed to be the most sensible to changes in organic fertilization (Sparling et al. 1998). All fertilized treatments showed increased C_{hwl} content in topsoil as compared with non-fertilized control (Table 3). Application of digestate with straw increased C_{hwl} content by 8%, the highest increase of C_{hwl} in this treatment is associated with application of straw as a source of degradable organic matter.

Soil microbial biomass is the living component of SOM and it is involved in nutrient transformation and storage. C-biomass content ranged in the assessed time period from 127–181 μg/g soil, low C_{mic} was found in non-fertilized control. Both organic amendments (digestate and cattle slurry) as well as the mineral fertilization caused increases in C_{mic} compared to the control non-fertilized soil. The highest increase of C_{mic} was recorded in Dig + St (43.2% increase) (Table 3). Straw application together with the digestate is a good source of organic C, easily mineralizable N from digestate supports the degradation of straw and increases microbial biomass and soil microbial activity. Alburquerque et al. (2012) mentioned that digestate addition to soil did not provoke any significant effect on total organic carbon but caused increases in C_{mic} and N_{mic} compared to the control soil. Since actual C-biomass responds to seasonal weather, crop input and fertilization, measurements of a simple index, such as C_{mic}/C_{tot} ratio can clarify the carbon availability for microorganisms, degree of conversion to microbial biomass C and the stabilisation or losses of soil carbon (Melero et al. 2007). In our experiment, high C_{mic}/C_{tot} ratio (39.7% higher compared to control) was recorded for digestate + straw where the increase of C-biomass was the highest as compared with other treatments. Liu et al. (2010) found the lowest ratios in N fertilized or control soils, and the highest in farmyard manure + NP.

Average intensities of hydrophobic components derived from FTIR spectra for individual treatments are shown in Table 4. All kinds of fertilization increased the amount of hydrophobic components in SOM as compared to non-fertilized control. Statistically significant increase (by 45.5%) was recorded for application of digestate + straw followed by digestate without straw. High positive correlations were found between hydrophobic components in SOM and C_{hwl} (r = 0.988; $P \geq 0.05$) and C_{mic} (r = 0.964; $P \geq 0.05$). Demyan et al. (2012) found a positive correlation between the same peak area of FTIR spectra and C_{hwl} as the present study. Such a positive correlations indicate the hypothesized labile nature of the compounds related to this peak area.

N_{tot} content ranged in the assessed time period from 0.157–0.160% and differences among treatments were minimal (Table 4) although nitrogen doses varied and for example mineral NPK fertilization gave 120 kg N/ha. From the results it is evident that most of the applied mineral N from NPK and mineralized nitrogen from digestate and cattle slurry was utilized by plants during vegetation or was partly lost from soil by denitrifica-

doi: 10.17221/530/2015-PSE

Table 4. Average hydrophobic components of soil organic matter and total organic nitrogen (N_{tot}) in soil samples from plots under different fertilization treatments (experimental site: Prague-Ruzyně)

Treatment	Hydrophobic components (intensity FTIR spectra)	N_{tot} (%)	C_{tot}/N_{tot}
Control	0.536 ± 0.025	0.157 ± 0.001	10.66 ± 0.01
Dig	0.639 ± 0.038	0.160 ± 0.001	10.69 ± 0.07
Dig + St	0.780 ± 0.035	0.159 ± 0.002	10.62 ± 0.17
NPK	0.588 ± 0.019	0.158 ± 0.002	10.71 ± 0.20
CSl	0.599 ± 0.068	0.160 ± 0.002	10.45 ± 0.17

Control – without organic or mineral fertilization; Dig – digestate; Dig + St – digestate + straw; NPK – mineral fertilization; CSl – cattle slurry; C_{tot} – total organic carbon

tion, volatilization or leaching (Meng et al. 2005). C/N ratio in the soil does not differ significantly between individual treatments and ranged from 10.45–10.71 (Table 4). The results obtained in this field experiment indicate that digestate with the density of the liquid phase (dry weight 6.2%) and N content (6.1% in dry weight) is close to cattle slurry (dry weight 7%, N content in dry weight 4.8%) but it is rather similar to mineral N fertilizer by form of the contained nitrogen and rate of N utilization by plant. Fertilization with digestate brings an effect on crop yields increase, but does not improve significantly the level of organic matter in the soil, so in longer-term it is necessary to add organic matter from other sources.

REFERENCES

Alburquerque J.A., de la Fuente C., Campoy M., Carrasco L., Nájera I., Baixauli C., Caravaca F., Roldán A., Cegarra J., Bernal M.P. (2012): Agricultural use of digestate for horticultural crop production and improvement of soil properties. European Journal of Agronomy, 43: 119–128.

Arthurson V. (2009): Closing the global energy and nutrient cycles through application of biogas residue to agricultural land – Potential benefits and drawbacks. Energies, 2: 226–242.

Demyan M.S., Rasche F., Schultz E., Breulmann M., Müller T., Cadisch G. (2012): Use of specific peaks obtained by diffuse reflectance Fourier transform mid-infrared spectroscopy to study the composition of organic matter in a Haplic Chernozem. European Journal of Soil Science, 63: 189–199.

Ellerbrock R.H., Gerke H.H., Bachmann J., Goebel M.-O. (2005): Composition of organic matter fractions for explaining wettability of three forest soils. Soil Science Society of America Journal, 69: 57–66.

Galvez A., Sinicco T., Cayuela M.L., Mingorance M.D., Fornasier F., Mondini C. (2012): Short term effects of bioenergy by-products on soil C and N dynamics, nutrient availability and biochemical properties. Agriculture, Ecosystems and Environment, 160: 3–14.

Garfí M., Gelman P., Comas J., Carrasco W., Ferrer I. (2011): Agricultural reuse of the digestate from low-cost tubular digesters in rural Andean communities. Waste Management, 31: 2584–2589.

Johansen A., Carter M.S., Jensen E.S., Hauggard-Nielsen H., Ambus P. (2013): Effects of digestate from anaerobically digested cattle slurry and plant materials on soil microbial community and emission of CO_2 and N_2O. Applied Soil Ecology, 63: 36–44.

Kubát J., Lipavský J. (2006): Steady state of the soil organic matter in long-term field experiments. Plant, Soil and Environment, 52: 9–14.

Kouřimská L., Poustková I., Babička L. (2012): The use of digestate as replacement of mineral fertilizers for vegetables growing. Scientia Agriculturae Bohemica, 43: 121–126.

Liu E., Yan C., Mei X., He W., Bing S.H., Ding L., Liu Q., Liu S., Fan T. (2010): Long-term effect of chemical fertilizer, straw, and manure on soil chemical and biological properties in northwest China. Geoderma, 158: 173–180.

Lošák T., Zatloukalová A., Szostková M., Hlušek J., Fryč J., Vítěz T. (2011): Comparison of the effectiveness of digestate and mineral fertilisers on yields and quality of kohlrabi (*Brassica oleracea*, L.). Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis, 59: 117–122.

Makádi M., Tomócsik A., Orosz V. (2012): Digestate: A New Nutrient Source – Review. In: S. Kumar (ed.): Biogas. Croatia, InTech Europe, 295–310.

Melero S., Madejón E., Ruiz J.C., Herencia J.F. (2007): Chemical and biochemical properties of a clay soil under dryland agriculture system as affected by organic fertilization. European Journal of Agronomy, 26: 327–334.

Meng L., Ding W.X., Cai Z.C. (2005): Long-term application of organic manure and nitrogen fertilizer on N_2O emissions, soil

doi: 10.17221/530/2015-PSE

quality and crop production in a sandy loam soil. Soil Biology and Biochemistry, 37: 2037–2045.

Merbach I., Schulz E. (2013): Long-term fertilization effects on crop yields, soil fertility and sustainability in the static fertilization experiment Bad Lauchstädt under climatic conditions 2001–2010. Archives of Agronomy and Soil Science, 59: 1041–1057.

Möller K., Stinner W., Deuker A., Leithold G. (2008): Effects of different manuring systems with and without biogas digestion on nitrogen cycle and crop yield in mixed organic dairy farming systems. Nutrient Cycling in Agroecosystems, 82: 209–232.

Möller K., Müller T. (2012): Effects of anaerobic digestion on digestate nutrient availability and crop growth: A review. Engineering in Life Sciences, 12: 242–257.

Schulz E. (1997): Characterization of soil organic matter (SOM) on the degree of their feasibility and their significance for transformation processes for nutrients and pollutants. Archives of Agronomy and Soil Science, 41: 465–483.

Šimon T. (2007): Characterization of soil organic matter in long-term fallow experiment with respect to the soil hydrophobicity and wettability. Soil Water Research, 2: 96–103.

Šimon T., Kunzová E. (2013): Effect of fertilization with digestate on yield of spring barley and soil quality. Úroda, 5: 27–32. (In Czech)

Sparling G., Vojvodic-Vukovic M., Schipper L.A. (1998): Hot-water-soluble C as a simple measure of labile soil organic matter: The relationship with microbial biomass C. Soil Biology and Biochemistry, 30: 1469–1472.

Tambone F., Scaglia B., D'Imporzano G., Schievano A., Orzi V., Salati S., Adani F. (2010): Assessing amendment and fertilizing properties of digestates from anaerobic digestion through a comparative study with digested sludge and compost. Chemosphere, 81: 577–583.

Vance E.D., Brookes P.C., Jenkinson D.S. (1987): An extraction method for measuring soil microbial biomass C. Soil Biology and Biochemistry, 19: 703–707.

Vaneeckhaute C., Meers E., Michels E., Buysse J., Tack F.M.G. (2013): Ecological and economic benefits of the application of bio-based mineral fertilizers in modern agriculture. Biomass and Bioenergy, 49: 239–248.

Received on August 21, 2015
Accepted on October 13, 2015

Corresponding author:

Ing. Tomáš Šimon, CSc., Výzkumný ústav rostlinné výroby, v.v.i., Drnovská 507, 161 06 Praha 6 – Ruzyně, Česká republika; e-mail: simont@vurv.cz