doi: 10.17221/16/2016-PSE

The effect of fertilisation with digestate on kohlrabi yields and quality

T. Lošák[1], J. Hlušek[1], T. Válka[1], J. Elbl[2], T. Vítěz[3], H. Bělíková[4], E. Von Bennewitz[5]

[1]*Faculty of Regional Development and International Studies, Mendel University in Brno, Brno, Czech Republic*
[2]*Faculty of Forestry and Wood Technology, Mendel University in Brno, Brno, Czech Republic*
[3]*Faculty of AgriSciences, Mendel University in Brno, Brno, Czech republic*
[4]*Department of Technologies, Research and Breeding Institute of Pomology Holovousy Ltd., Hořice, Czech Republic*
[5]*Department of Agronomy, Catholic University of the Maule, Curicó, Chile*

ABSTRACT

Three treatments were used in a two-year (2014–2015) vegetation pot experiment with kohlrabi of the cv. Moravia: (1) untreated control; (2) digestate; (3) digestate + phosphorus (P). The nitrogen (N) rate was the same in treatments 2–3. There were significant differences between years in all parameters. The weight of single kohlrabi bulbs in the unfertilised control was significantly lower in both years (33.1–46.9%) than in the digestate treatment (100%). Digestate supplemented with P (treatment 3) increased the bulb yield significantly by 11.0–14.3% compared with pure digestate (treatment 2). In both years the content of bulb nitrates (mg NO_3^-/kg FM (fresh matter)) was significantly the lowest in the unfertilised control (135 and 163, respectively). After digestate applications the nitrates content (mg NO_3^-/kg FM) increased significantly in both years, i.e. to 315–327 (2014) and to 486–509 (2015) compared to unfertilised control. In two years the content of ascorbic acid (mg/kg FM) did not differ among the three treatments (274–288 in 2014 and 311–329 in 2015). Digestates can be recommended for kohlrabi fertilisation prior to planting.

Keywords: anaerobic digestion; vegetable; biogas plants; renewable energy; *Brassica oleracea*

The number of biogas stations in the Czech Republic has recently increased considerably; as of 1 January 2014 some 500 biogas plants were registered of which 378 are agricultural biogas plants with installed electric energy of 392 MW. The estimated annual digestate production ranges around 7.9 mil t and the biogas stations are deployed irregularly in the regions. On that account practical problems frequently arise how to utilise the digestate effectively and/or where to apply it (in compliance with legislation – for example: The Nitrates Directive and Restrictions in the Vulnerable Areas). Considering the fact that digestate is produced during the whole year, possibilities are being sought of using it not only to fertilise arable crops but also vegetables. Whereas information on using digestate to fertilise arable crops is relatively abundant, in the case of vegetables it is vice versa (Dostál et al. 2015).

Manures from stables, crop residues, wastes from the food industry, municipal wastes, and dedicated energy crops are the main feedstocks for anaerobic digestion (AD) in biogas plants. The residual product of AD, called digestate (= biogas effluents = biogas residues, or biogas slurry, when animal manures are digested), is usually used as

Supported by the Internal Grant Agency of the Faculty of AgriSciences Mendelu in Brno, Project No. TP 8/2014, and by the Internal Grant Agency of the Faculty of Regional Development and International Studies Mendelu in Brno, Project No. 10/2015.

doi: 10.17221/16/2016-PSE

a fertiliser (Möller and Müller 2012). Biogas and digestate are the end-products of anaerobic digestion of organic raw material which is an important source of renewable energy.

However, wide-scale biogas production raises a number of new questions, including the subsequent use of anaerobic fermentation residues – digestate (Cigánek et al. 2010). Field and pot trials to date report positive effects of digestate application to arable land in terms of yields (Stinner et al. 2008, Arthurson 2009, Gunnarsson et al. 2010) or no significant effects (Ross et al. 1989, Bath and Elfstrand 2008). Literature on the application of digestates as fertilisers for vegetables is very scarce. Expert opinion on the properties and possibilities for practical use of digestate as an organic fertiliser is divided (Odlare et al. 2008, Kolář et al. 2008, 2010, Möller et al. 2011, Lošák et al. 2011). Digestion is associated with large losses of organic carbon (C) (Möller 2009). Möller and Müller (2012) reported that as much as 95% of the feedstock organic matter is degraded, depending on the feedstock composition. However, the digestate produced is rich in nitrogen (N) and has a high NH_4^+-N/total N ratio, making it potentially suitable as a fertiliser. Digestates contain a high amount of nitrogen and potassium (Šimon et al. 2015), while the phosphorus (P) content, among other macronutrients, is significantly lower. Besides macronutrients, digestates contain micronutrients, too. The application of digestates can therefore save considerable costs for the purchase of mineral fertilisers (Lošák et al. 2011).

The aim of this 2-year study was to compare the effectiveness of digestate and digestate + P on yield, nitrate- and ascorbic acid content of kohlrabi. The novelty of our approach is patterned on the following working hypothesis: (1) digestate is a suitable fertiliser for kohlrabi; (2) application of digestate + P will improve the kohlrabi yield more than application of digestate only (with respect to low soil phosphorus content); (3) expectancy of no differences in kohlrabi ascorbic acid contents among used fertilisers.

Table 2. Treatments of the experiment

Treatment	Description	Rate of nutrients (g/pot): N-P-K-Mg	Fertiliser used
1	control	0	–
2	digestate	1.5-0.24-1.35-0.14	digestate
3	digestate + P	1.5-0.48-1.35-0.14	digestate, TSP

TSP – triple superphosphate (19.6% P)

Table 1. Agrochemical characteristics of the soil prior to establishment of the trial (mg/kg)

pH_{CaCl_2}	P	K	Mg
7.6	49	166	342
Alkali	low	satisfactory	good

MATERIAL AND METHODS

The 2-year vegetation pot experiment was established on 27 May 2014 and on 28 April 2015 in the outdoor vegetation hall of the Mendel University in Brno. Mitscherlich vegetation pots were filled with 6 kg of medium heavy soil characterised as fluvial soil; Table 1 gives the agrochemical characteristics of the soil prior to the establishment of the trial (Mehlich III). Soil pH was determined in the 0.01 mol/L $CaCl_2$ (10 g soil/50 mL 0.01 mol/L $CaCl_2$). The soil samples were shaken on an overhead shaker for 1 h, then the suspension was left for 1 h and then measured with the pH meter WTW 315i/SET (WTW GmbH, Weilheim, Germany).

Table 2 shows the individual treatments of the experiment. Each treatment included 4 repetitions.

The dry matter content of the digestate was 6.99%, pH 8.16 and C:N ratio 4.8:1. Table 3 gives the analysis of the digestate for the total content of nutrients. Determination of P, K, Ca and Mg in the digestate was as follows: 0.5 g dried homogenized digestate + 2 mL concentrated HNO_3 + 6 mL concentrated HCl. Samples were mineralized in the microwave system. Measurement: ICP-OES spectrometer ARCOS (Spectro, Kleve, Germany). The total N content in digestate was determined according to the Dumas method (nitrogen combustion method) – Dumatherm (Gerhardt, Königswinter, Germany).

Digestate and digestate + P fertiliser were applied in the form of watering and were thoroughly mixed with the entire amount of soil in the pot. The dose of P-fertiliser (triple superphosphate) was 0.24 g/pot, so that the total rate of phosphorus in treatment 3 was 0.48 g/pot. Two seedlings of the early kohlrabi cv. Moravia were planted 8 days (2014) and 7 days (2015) after fertilisation. The pots were watered to

Table 3. Total nutrient content (%) of the digestate used to study the response of kohlrabi

	N	P	K	Ca	Mg
Fresh matter	0.537	0.087	0.483	0.108	0.051

doi: 10.17221/16/2016-PSE

a level of 60% of the maximal capillary capacity and were kept free of weeds. The bulbs were harvested at full maturity on 18 July 2014 and on 29 June 2015. Immediately after harvest the individual bulbs without leaves were weighed.

Nitrates estimation in bulbs. Nitrate concentration (mg NO_3^-/kg FM) was determined in the fresh matter of bulbs with a potentiometer using the ion selective electrode (Magic XBC, GRYF HB Ltd., Havlíčkův Brod, Czech Republic).

Ascorbic acid estimation in bulbs. The content of ascorbic acid (mg NO_3^-/kg FM) was determined in fresh matter using the capillary izotachoforesy method (HP 1090 Series II, detector diode-array option 083, Hewlett Packard, Miami, USA).

Statistical analysis. The measured values of bulb weight, content of nitrates and ascorbic acid were analysed by the analysis of variance (ANOVA at level $\alpha = 0.05$; two factors were always compared – differences between years and in each year) in combination with the Fisher *LSD* test. All data were analysed using the Statistica 10 CZ software (Round Rock, USA) and processing of the measured data was performed in Microsoft Excel 2013 (Redmond, USA).

RESULTS AND DISCUSSION

Weight of single bulbs. A deficiency of NO_3^--N in the soil reduces yields (Steingrobe and Schenk 1991) because a characteristic of kohlrabi is the high uptake of N from the soil (Feller and Fink 1997). Sharof and Wier (1994) studied the minimum amount of N required for vegetable crops, including kohlrabi, in relation to components of N balance in the soil and found that N requirements were invariably lower than values from field trials.

As early as the first stages of growth in this pot study there was a visible difference between the fertilised treatments and the unfertilised control. The plants in the latter had a lighter colour and the growth of the aboveground biomass was markedly slower. At harvest, symptoms of P deficiency (violet discolouration) were detected on bulbs of the control treatment which was the result of a low P supply in the soil and unsuitable pH value for P uptake.

Kohlrabi yields in g/plant (Table 4) were significantly different in the individual years. The weight of single kohlrabi bulbs in the unfertilised control was significantly lower in both years (33.1–46.9%) than in the digestate treatment (100%). There was thus an obvious positive synergistic effect of additional nutrients in digestates (especially N and K) on yields. This confirms that N is the decisive element in terms of yields as reported previously by Feller and Fink (1997) and Lošák et al. (2011). In experiments lasting several years Stinner et al. (2008) also reported positive effects of three different types of digestate (fermented clover-grass mixture, cover crops and post-harvest residues) on wheat yields. Similarly, Bath and Elfstrand (2008) reported higher yields of leek after the application of digestate compared with fertilisation with compost. On soil with a low or satisfactory supply of available nutrients Cigánek et al. (2010) discovered that grain yields of winter wheat increased by 30.0–63.9% and seed yields of winter rape by 38.5–57.7% compared with the unfertilised control. In our experiment (Table 4) digestate supplemented with P (treatment 3) increased the bulb yield significantly by 11.0–14.3% compared with pure digestate (treatment 2). Soil used in this experiment contained a low supply of available P, so that addition of water soluble phosphorus ($H_2PO_4^-$) caused better nutrients utilization efficiency (treatment 3).

Content of nitrates in bulbs. Kohlrabi is a vegetable prone to a higher risk of nitrate accumulation in tissues. The concentration of NO_3^- in plants

Table 4. The effect of fertilisers on kohlrabi bulb weights in both years

Treatment	Description	2014		2015	
		(g)	(rel. %)	(g)	(rel. %)
1	control	42^{aA}	33.1	69^{aB}	46.9
2	digestate	127^{bA}	100.0	147^{bB}	100.0
3	digestate + P	141^{cA}	111.0	168^{cB}	114.3

Mean values of kohlrabi bulb weights ($n = 4$). Different small letters indicate significant differences at the level of $\alpha = 0.05$ among individual treatments within the same year and different uppercase letters (A, B) indicate significant differences at the level of $\alpha = 0.05$ among individual years

doi: 10.17221/16/2016-PSE

Table 5. The effect of fertilisers on the content of nitrate (NO_3^-) in kohlrabi in both years

Treatment	Description	2014		2015	
		(mg/kg FM)	(rel. %)	(mg/kg FM)	(rel. %)
1	control	135^{aA}	41.2	163^{aB}	32.0
2	digestate	327^{bA}	100.0	509^{bB}	100.0
3	digestate + P	315^{bA}	96.3	486^{bB}	95.5

Mean values of kohlrabi bulb nitrates (n = 4). Different small letters indicate significant differences at the level of α = 0.05 among individual treatments within the same year and different uppercase letters (A, B) indicate significant differences at the level of α = 0.05 among individual years; FM – fresh matter

is affected primarily by species-specific factors, level of N fertilisation, type of fertiliser, the plant organ in question, growth stage and the S concentration in the tissues (Marschner 2002, Lošák et al. 2008). In both years (Table 5) the content of bulb nitrates (mg NO_3^-/kg FM) was significantly the lowest in the unfertilised control (135 and 163, respectively). After digestate applications the nitrates content (mg NO_3^-/kg FM) increased significantly in both years, i.e. to 315–327 (2014) and to 486–509 (2015) compared to unfertilised control. There were no significant differences between treatments 2 and 3.

In their experiments with kohlrabi of the cv. Segura F1 Lošák et al. (2011) found out the similar results – the nitrate content in kohlrabi was the highest after the application of urea (678 mg/kg of FM), while it decreased significantly in the digestate treatment to 228 mg/kg of FM. Unfertilised control had the lowest nitrate content – 41 mg/kg of FM (Lošák et al. 2011). The reason could be that the digestate contains a specific proportion of organic N (25–50%) which is subject to mineralisation after a certain period (Kirchmann and Witter 1992). It can be assumed that during the short period of kohlrabi growth (approx. 6–7 weeks) only part of the organically bound nitrogen was mineralised. Therefore mineral N-NH_4^+ from the digestate (or after its nitrification N-NO_3^-) was available to the plants and was sufficient for yield formation but increased the nitrate content in the bulbs less than urea treatment (benefit to human health). Urea is a readily soluble mineral fertiliser and plants can take up N from urea in the form of whole molecules or after decomposition as NH_4^+ or NO_3^- (Mengel and Kirkby 2001).

Content of ascorbic acid in bulbs. Vitamin C, including ascorbic acid and dehydroascorbic acid, is one of the most important nutritional quality factors in many horticultural crops and has many biological activities in the human body. The content of vitamin C in vegetables can be influenced by various factors such as genotypic differences, preharvest climate conditions and cultural practices, maturity and harvesting method, and post-harvest handling procedures (Lee and Kader 2000).

Table 6 shows the contents of ascorbic acid in the kohlrabi bulbs. In the two years the content of ascorbic acid (mg/kg FM) did not differ among the three treatments (274–288 in 2014 and 311–329 in 2015). However, in a previous experiment with kohlrabi of the cv. Segura F1 (Lošák et al. 2011) the content of ascorbic acid was found to be higher in all the fertilised treatments (772–789 mg/kg FM) as compared to the unfertilised treatment (511 mg/kg FM). Previous studies differ in their conclusions regarding the effect of nitrogenous fertilisation on the content of vitamin C. Mozafar (1993) reported

Table 6. The effect of fertilisers on the content of ascorbic acid in kohlrabi in both years

Treatment	Description	2014		2015	
		(mg/kg FM)	(rel. %)	(mg/kg FM)	(rel. %)
1	control	281^{aA}	102.6	311^{aB}	94.5
2	digestate	274^{aA}	100.0	329^{aB}	100.0
3	digestate + P	288^{aA}	105.1	326^{aB}	99.1

Mean values of kohlrabi bulb ascorbic acid (n = 4). Different small letters indicate significant differences at the level of α = 0.05 among individual treatments within the same year and different uppercase letters (A, B) indicate significant differences at the level of α = 0.05 among individual years; FM – fresh matter

doi: 10.17221/16/2016-PSE

that nitrogen fertilisers, especially at high rates, seem to decrease the concentration of vitamin C in many different vegetables. Similarly, according to Smatanová et al. (2004), the content of ascorbic acid in spinach decreased from 57.5 to 51.9 ppm when the rate of nitrogen increased from 0.6–0.9 g N/pot. In contrast, Nilsson (1980) reported that nitrogen fertilisation did not affect the content of vitamin C in cauliflower, while Maurya et al. (1992) showed that with a higher rate of nitrogen cauliflower contained significantly more vitamin C.

REFERENCES

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.

Bath B., Elfstrand S. (2008): Use of red clover-based green manure in leek cultivation. Biological Agriculture and Horticulture: An International Journal for Sustainable Production Systems, 25: 269–286.

Cigánek K., Lošák T., Szostková M., Zatloukalová A., Pavlíková D., Vítěz T., Fryč J., Dostál J. (2010): Verification of the effectiveness of fertilisation with digestates from biogas stations on yields of winter rape and winter wheat and changes in some agrochemical soil properties. Agrochemistry, 50: 16–21.

Dostál J., Lošák T., Hlušek J. (2015): Digestate – Mythos and reality in relation to soil fertility. In: Proceeding of the Internation Conference Maize in Practice 2015, January 7, 2015, Plzeň, 24–31. (In Czech)

Feller C., Fink M. (1997): Nitrogen uptake of kohlrabi, estimated by growth stages and an empirical growth model. Journal of Plant Nutrition and Soil Science, 160: 589–594.

Gunnarsson A., Bengtsson F., Caspersen S. (2010): Use efficiency of nitrogen from biodigested plant material by ryegrass. Journal of Plant Nutrition and Soil Science, 173: 113–119.

Kirchmann H., Witter E. (1992): Composition of fresh aerobic and anaerobic farm animal dungs. Bioresource Technology, 40: 137–142.

Kolář L., Kužel S., Peterka J., Štindl P., Plát V. (2008): Agrochemical value of organic matter of fermenter wastes in biogas production. Plant, Soil and Environment, 54: 321–328.

Kolář L., Kužel S., Peterka J., Borová-Batt J. (2010): Agrochemical value of the liquid phase of wastes from fermenters during biogas production. Plant, Soil and Environment, 56: 23–27.

Lee S.K., Kader A.A. (2000): Preharvest and postharvest factors influencing vitamin C content of horticultural crops. Postharvest Biology and Technology, 20: 207–220.

Lošák T., Hlušek J., Kráčmar S., Varga L. (2008): The effect of nitrogen and sulphur fertilization on yield and quality of kohlrabi (*Brassica oleracea* L.). Revista Brasileira de Ciencia do Solo, 32: 697–703.

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, LIX: 117–122.

Marschner H. (2002): Mineral Nutrition of Higher Plants. 2nd Ed. London, Academic Press.

Maurya A.N., Chaurasia S.N.S., Reddy Y.R.M. (1992): Effect of nitrogen and molybdenum levels on growth, yield and quality of cauliflower (*Brassica oleracea* var. Botrytis) cv. Snowball-16. Haryana Journal of Horticultural Sciences, 21: 232–235.

Mengel K., Kirkby E.A. (2001): Principles of Plant Nutrition. 5th Ed. London, Kluwer Academic Publishers.

Möller K. (2009): Influence of different manuring systems with and without biogas digestion on soil organic matter and nitrogen inputs, flows and budget in organic cropping systems. Nutrient Cycling in Agroecosystems, 84: 179–202.

Möller K., Schulz R., Müller T. (2011): Effects of setup of centralized biogas plants on crop acreage and balances of nutrients and soil humus. Nutrient Cycling in Agroecosystems, 89: 303–312.

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.

Mozafar A. (1993): Nitrogen fertilizers and the amount of vitamins in plants: A review. Journal of Plant Nutrition, 16: 2479–2506.

Nilsson T. (1980): The influence of soil type, nitrogen and irrigation on yield, quality and chemical composition of cauliflower. Swedish Journal of Agricultural Research, 10: 65–75.

Odlare M., Pell M., Svensson K. (2008): Changes in soil chemical and microbiological properties during 4 years of application of various organic residues. Waste Management, 28: 1246–1253.

Ross D.J., Tate K.R., Speir T.W., Stewart D.J., Hewitt A.E. (1989): Influence of biogas-digester effluent on crop growth and soil biochemical properties under rotational cropping. New Zealand Journal of Crop and Horticultural Science, 17: 77–87.

Sharof H.C., Wier U. (1994): Calculation of nitrogen immobilization and fixation. Gartenbau, Hannover, Germany. Bodenkunde, 157: 11–16.

Smatanová M., Richter R., Hlušek J. (2004): Spinach and pepper response to nitrogen and sulphur fertilization. Plant, Soil and Environment, 50: 303–308.

Steingrobe G., Schenk M.K. (1991): Influence of nitrate concentration at the root surface on yield and nitrate uptake of kohlrabi (*Brassica oleracea-gongyloides*, L.) and spinach (*Spinacia oleracea*, L.). Plant and Soil, 135: 205–211.

Stinner W., Möller K., Leithold G. (2008): Effects of biogas digestion of clover/grass-leys, cover crops and crop residues on nitrogen cycle and crop yield in organic stockless farming systems. European Journal of Agronomy, 29: 125–134.

Šimon T., Kunzová E., Friedlová M. (2015): The effect of digestate, cattle slurry and mineral fertilization on the winter wheat yield and soil quality parameters. Plant, Soil and Environment, 61: 522–527.

Received on January 8, 2016
Accepted on May 20, 2016

Corresponding author:
Prof. Ing. Tomáš Lošák, Ph.D., Mendelova univerzita v Brně, Fakulta regionálního rozvoje a mezinárodních studií, Ústav environmentalistiky a přírodních zdrojů, Zemědělská 1, 613 00 Brno, Česká republika; e-mail: losak@mendelu.cz