

DIGESTATE IS EQUAL OR A BETTER ALTERNATIVE TO MINERAL FERTILIZATION OF KOHLRABI

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Abstract

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In a one-year vegetation pot experiment, we compared the effect of digestate from a biogas station and mineral fertilisers on yield and quality parameters of kohlrabi, variety Segura F1. Four treatments were used in the trial: 1) untreated control, 2) urea, 3) digestate, 4) urea, triple super phosphate, KCl, MgSO_4 . The N dose was the same in treatments 2–4, 1.5 g N/pot. In treatment 4 the P, K and Mg doses corresponded to those supplied in the digestate treatment (3).

The weight of single kohlrabi bulbs in the unfertilised control was significantly lower (36.2%) than in the urea treatment (100%) and the other fertilised treatments. After application of digestate (treatment 3) and mineral fertilisers (treatment 4), the weight of single bulbs significantly increased by 36.2 and 33.6%, respectively, compared with the urea treatment (2). The content of ascorbic acid did not differ between the fertilised treatments (282–301 mg/kg), but was significantly lower than in the unfertilised control (334 mg/kg). There were significant differences between all fertilised treatments (2, 3, 4) in bulb nitrate content (745, 187, 462 mg NO_3^- /kg fresh matter, respectively). After digestate application the content decreased significantly, to 187 mg NO_3^- /kg fresh matter. The soil N_{min} content after harvest varied between 4.19–5.79 mg/kg in all fertilised treatments and the N-NH_4^+ form prevailed over N-NO_3^- only in the digestate treatment (3.45/2.34 mg/kg). We recommend the use of digestate to kohlrabi as it results in comparable or better yield and qualitative parameters of kohlrabi compared with mineral fertilizers.

ascorbic acid, mineral fertilizers, mineral nitrogen, nitrate, yields, urea

Biogas and digestate are the end-products of anaerobic digestion of organic raw material, which is an important source of renewable energy. Anaerobic digestion has been known for centuries, but rising prices of fossil fuel and increasing atmospheric pollution have boosted the interest in this process over recent years (Holm-Nielsen *et al.*, 2009; Weiland, 2010) and have made anaerobic digestion attractive to investors and consumers (Midillia *et al.*, 2006; Angelidaki *et al.*, 2011).

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 yield (Stinner *et al.*, 2008; Arthurson, 2009; Gunnarsson *et al.*, 2010) or no significant effects (Ross *et al.*, 1989; Bath and Elfstrand, 2008). Expert opinion is divided on the properties and possibilities for practical use of digestate as an organic fertiliser (Odlare *et al.*, 2008; Kolář *et al.*, 2008, 2010; Möller *et al.*, 2010, 2011; Lošák *et al.*, 2011). Digestion is associated with large losses of organic C (Möller, 2009). During the digestion process, 24–80% of organic dry matter is transformed to methane and carbon dioxide (Amon

and Döhler, 2004). However, the digestate produced is rich in N and has a high $\text{NH}_4^+\text{-N}$ /total N ratio, making it potentially suitable as a fertiliser.

The aim of this study was to compare the effectiveness of digestate and mineral fertilisers on yield and qualitative parameters of kohlrabi and to determine changes in post-harvest soil mineral nitrogen.

MATERIALS AND METHODS

The pot experiment was established on 20 May 2011; Mitscherlich vegetation pots were filled with 6 kg of medium heavy soil characterised as fluvial soil, the agrochemical properties of which are summarised in Table I. The experiment involved four treatments, as shown in Table II.

The digestate (C/N ratio 4:1) was obtained from a biogas station which uses pig slurry (approx. 10 t/day) and maize silage from hybrid KWS 1393 (approx. 16 t/day) as the input raw material. Prior to the experiment, the digestate was analysed for content of nutrients (Table III) and hazardous elements (Table IV). The contents of all hazardous elements (Cd, Pb, Hg, As, Cr, Cu, Mo, Ni, Zn) were below the limit specified in EU Regulation 271/2009 Coll.

Mineral fertilisers and digestate were applied during watering as solutions and were thoroughly mixed with the entire amount of soil in the pot, with 4 replicate pots per treatment. Two seedlings of kohlrabi variety Segura F1 were planted per pot 10 days after fertilisation. The pots were watered to a level of 60% of the maximum water-holding capacity and were kept free of weeds. The bulbs were harvested at full maturity on 19 July 2011. Immediately after harvest, individual bulbs without

leaves were weighed. Nitrate concentration (mg NO_3^-/kg) in the fresh matter of bulbs was determined with a potentiometer using ion selective electrode (ISE). The content of ascorbic acid was determined in fresh matter using the capillary **isotachophoresis** method.

The results were processed statistically using variance analysis, followed by testing according to Scheffe ($P < 0.05$).

RESULTS AND DISCUSSION

a) Weight of single bulbs

A characteristic of kohlrabi is high uptake of N from the soil (Feller and Fink, 1997), and therefore deficiency of NO_3^- -N in the soil reduces yields (Steingrobe and Schenk, 1991). 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 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 low P supply to the soil and unsuitable pH value for P uptake.

Weight of single bulbs is shown in Table V. The weight of the unfertilised bulbs (treatment 1) was 63.8% lower than in the treatment fertilised with nitrogen only (2). This confirms that N was the

I: Agrochemical characteristics of the soil prior to trial establishment (Mehlich III)

pH/ CaCl_2	mg/kg			
	P	K	Ca	Mg
7.5	34	159	6,262	303
alkali	low	satisfactory	very high	good

II: Experimental set up to study the effect of digestate and mineral fertilization on kohlrabi

Treatment No.	Description	Dose of nutrients (g/pot): N-P-K-Mg	Fertiliser used
1	Untreated control	0	-
2	N	1.5	urea
3	Digestate	1.5-0.18-0.69-0.08	digestate
4	N, P, K, Mg	1.5-0.18-0.69-0.08	urea, triple superphosphate, KCl, MgSO_4

III: Nutrient content of the digestate used for studying responses of kohlrabi

%	Nutrients				
	N	P	K	Ca	Mg
in dry matter (DM)	11.4	1.37	5.2	2.02	0.62
in fresh matter (FM)	0.72	0.09	0.31	0.13	0.04

IV: Contents of metals in the digestate used for studying responses of kohlrabi and maximum admissible amounts

	mg/kg dry matter								
	Cd	Pb	Hg	As	Cr	Cu	Mo	Ni	Zn
Content	0.1	2.4	0.2	0.2	9.1	99	4.6	8.6	481
Max.*	2	100	1	20	100	250	20	50	1,200

*maximal admissible amount according to EU Regulation 271/2009 Coll.

V: The effect of digestate and mineral fertilizer on kohlrabi bulb weights

Treatment No.	Description	Weight of one bulb	
		g	rel. %
1	Untreated control	42 a	36.2
2	N	116 b	100.0
3	Digestate	158 c	136.2
4	N, P, K, Mg	155 c	133.6

Different letters (a, b, c) indicate significant differences between treatments

VI: The effect of digestate and mineral fertilizer on content of ascorbic acid and nitrate in kohlrabi

Treatment No.	Description	Content of ascorbic acid		Nitrate content	
		mg/kg FM	rel. %	mg/kg FM	rel. %
1	Untreated control	334 b	118.4	63 a	8.5
2	N	282 a	100.0	745 d	100.0
3	Digestate	301 a	106.7	187 b	25.1
4	N, P, K, Mg	291 a	103.2	462 c	62.0

FM – fresh matter; Different letters (a, b, c) indicate significant differences between treatments

decisive element in terms of yield, as reported previously by Hlušek *et al.* (2002) and Feller and Fink (1997). The weight of single bulbs fertilised with the digestate (treatment 3) and with mineral fertilisers (treatment 4) was significantly higher, by 36.2 and 33.6% respectively, than the weight of those fertilised with nitrogen only (treatment 2). There was thus an obvious positive synergistic effect of additional nutrients (especially P, K, Mg) on yield in treatments 3 and 4. No significant differences were observed between treatments 3 and 4. 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 yield of winter wheat increased by 30.0–63.9% and seed yield of winter rape by 38.5–57.7% compared with the unfertilised control.

b) Content of ascorbic acid and nitrate 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, pre-harvest climate conditions and cultural practices, maturity and harvesting method, and post-harvest handling procedures (Lee and Kader, 2000).

Table VI shows the contents of ascorbic acid and nitrate in the kohlrabi bulbs. The content of ascorbic acid did not differ between the fertilised treatments (282–301 mg/kg), but it was significantly lower than in the unfertilised treatment (334 mg/kg). Previous studies differ in their conclusions regarding the effect of nitrogenous fertilisation on the content of vitamin C. Mozafar (1993) reported 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 to 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 dose of nitrogen, cauliflower contained significantly more vitamin C.

Kohlrabi is a vegetable prone to a higher risk of nitrate accumulation in tissues (Hlušek *et al.*, 2002). The concentration of NO_3^- in plants is affected primarily by species-specific factors, level of N fertilisation, the plant organ in question, growth stage and the S concentration in the tissues (Marschner, 2002; Lošák *et al.*, 2008).

VII: The effect of digestate and mineral fertilizer on content of mineral nitrogen (N_{\min}) in the soil after harvesting kohlrabi

Treatment No.	Description	mg/kg DM		
		$N-NH_4^+$	$N-NO_3^-$	N_{\min}
1	Untreated control	1.30	2.11	3.41 a
2	N	2.12	2.31	4.44 b
3	Digestate	3.45	2.34	5.79 c
4	N, P, K, Mg	2.06	2.13	4.19 b

Different letters (a, b, c) indicate significant differences between treatments

The lowest nitrate content was observed in the unfertilised control (63 mg/kg FM) and the second lowest in the digestate treatment (187 mg/kg FM) (Table VI). 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. 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 did not increase the nitrate content in the bulbs. The nitrate content was highest in the two treatments fertilised with nitrogen in the form of urea (745 mg/kg of FM in treatment 2 and 462 mg/kg of FM in treatment 4). 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).

c) Content of soil mineral nitrogen after harvest

Nitrogen is the nutrient that is most susceptible to transformations affecting its availability to plants. These transformations include mineralisation,

immobilisation, nitrification and denitrification, as well as leaching and ammonia volatilisation (Möller and Stinner, 2009). It is difficult to synchronise the supply of N from organic manures with the demands of crops for N (Pang and Letey, 2000). Soil microbial activity leads to N release that is not in synchronisation with plant nutrient demand (Dosch and Gutser, 1996). The elevated NH_4^+ -N concentration in the digestate used in this study indicates its potential suitability as a readily available N source.

The post-harvest content of N_{\min} in soil was lowest in the unfertilised treatment (3.41 mg/kg) (Table VII). Small but significant differences in the total content of N_{\min} (4.19–5.79 mg/kg) were observed among the other treatments. However, a great difference was observed in the forms of N present. $N-NH_4^+$ prevailed over $N-NO_3^-$ only in the digestate treatment (3.45/2.34 mg/kg), which had the highest N_{\min} content. Digestate has a large proportion of organically bound N (50–75%), which is available only after mineralisation, i.e. by ammonification and nitrification (Kirchmann and Witter, 1992). Nonetheless the results indicate that within the short duration of the experiment, only a minor amount of N was nitrified. For the plants to utilise more N from the digestate, a longer time period would be necessary.

SUMMARY

The results of this one-year trial show that the digestate fertiliser used produced kohlrabi bulbs of a similar weight to those produced in the mineral fertiliser treatments, indicating comparable rates of nutrient supply. In terms of qualitative parameters, all fertilisation with N reduced the ascorbic acid content in bulbs by about 9.9–15.6% compared with the unfertilised control. However, the nitrate content in bulbs was 2.5–4 times lower in digestate-fertilised bulbs than in both mineral-fertilised treatments. The post-harvest content of N_{\min} in the soil was higher after digestate application than in the urea-fertilised treatments and $N-NH_4^+$ prevailed over $N-NO_3^-$. Application of digestate can therefore replace mineral fertilisers in kohlrabi production, providing great cost savings. However digestates are poor in labile organic substances and the soil must be supplied these from other sources.

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