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Use of solid phase of digestate for production of growing horticultural substrates

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Abstract: Solid phase of digestate (SD) of agricultural biogas plants, containing undecomposed fibrous fractions of organic matter, is usable as a constituent of growing substrates. The content of soluble salts and available nutrients is limiting for SD addition into growing substrates. For addition of SD with initial 80% moisture its content of ammonium nitrogen and available potassium is limiting. The SD with natural moistness can be used in peat based substrates up to 10% volume. The content of ammonium nitrogen during the drying of SD with the use of waste heat from biogas plants is decreased. Optimal proportion of dry SD (dSD) in peat based substrates ranged from 20 to 40% volume. Peat based substrates with 20% volume of dSD had suitable physical and chemical (e.g. content of available potassium < 300 mg/l) properties. These dSD-peat growing substrates have been successfully tested in greenhouse experiments with pot plants (*Petunia, Impatiens,* and *Pelargonium*). The addition of dSD to peat based substrates increased air capacity and decreased easily available water content. However, the basic fertilization of the dSD-peat growing substrates is necessary to optimize the content of nutrients.

Keywords: biogas plant; ornamental gardening; plant nutrition; pot plants

Peat moss, as an organic material, constitutes the main growing substrate component because of its suitable physical properties, such as low bulk density and high total porosity. Peat can be used alone or in combination with other organic or inorganic components. In some countries, peat as a non-renewable natural resource begins to be limited for addition into substrates (Restrepo et al. 2013). Nevertheless, peat can be partly or even completely replaced by alternative components of substrates (i.e. compost, sawdust, mushroom medium, composted bark, crushed hydrophilic rock wool, coconut fibre, sewage sludge and many others) and their mixtures (Schmilewski 2008). The proportion of components with a high soluble salt content can cause certain limitations for plant growth and quality of products. Therefore, it is necessary to keep the max. proportion of these components up to 20% of volume in the substrate mixtures (Sonneveld, Voogt 2009).

The traditional alternative for peat replacement in growing substrates is compost which can present certain limitations mainly due to high soluble salt and available potassium contents. Therefore the proportion of compost in growing substrates is restricted. For basic fertilisation of substrate mixtures with such rich components as compost with high K and P contents and with sufficient contents of mi-

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cronutrient it is recommended to apply only nitrogen fertilisers (Carlile 2008; Rainbow 2009).

The biogas production by anaerobic fermentation of organic matter using purposefully grown biomass has been increasing in recent years producing large amounts of waste materials called digestate. Digestate is a mixture of soluble nutrients and stable soluble complexes called fugate and undecomposed organic material called separate or generally solid phase of digestate (SD) (Abubaker et al. 2012). The fibrous structure of the SD and stability of organic matter favourably affect physical properties of soils, modifies water/air ratio and can present suitable properties for plant production (Makadi et al. 2008; Torres-Climent et al. 2015). Its composition, chemical and physical properties are varied according to the origin of the raw material used as feeding material for anaerobic fermentation. Therefore, biogas plants can produce waste materials varying in macro and micronutrients contents (Abubaker et al. 2012). Anaerobic digestion process can allow to inactivate weed seeds, immobilize bacteria (*Salmonella, Escherichia coli, Listeria*), viruses and fungi which have great importance for using digestate as a fertiliser (Weiland 2010).

The solid phase of digestate can also be composted (Bustamante et al. 2013). Composting of SD can represent the way how to improve the quality of the feedstock and thus reduce the bad smell, the concentration of volatile compounds, moisture and the potential phytotoxicity. Composted SD can be used in ornamental nurseries as a replacement of peat for growing of pot plants (Crippa et al. 2013).

Thermal drying of SD with the utilization of waste heat from biogas plants can improve its transportation, volume mass, storage and sanitation. However thermal drying brings also some problems, i.e. ammonium nitrogen losses and possible atmospheric pollution by ammonia. The ammonia losses during drying can be decreased by acidification of SD before drying (Pantelopoulos et al. 2016) or by ammonia absorption from the gas leaving drier. Final dry SD product has defined ammonium nitrogen content.

Flowers planted in the experiment are relatively sensitive for nutrients and conductivity as well for pH values of the substrates. The *Petunia* plants belong among Fe-inefficient plants that very susceptibly react to pH values higher than 6.2 by lower Fe uptake followed by chlorosis and growth depression (Smith et al. 2004). The optimal pH substrate in aqueous solution ranging from 5.4 to 6.2 for *Petunia* plants and from 6.0 to 6.6 for *Impatiens* and *Pelargonium* plants (Fisher 2004). *Impatiens* plants are very sensitive to high soluble salt contents in growing substrates characterized by high electric conductivity (EC) of aqueous solution (Judd, Cox 1992).

The aim of our study was to evaluate the addition of dry solid phase of digestate (dSD) into peat based substrates with regard to the application rates and to determine the effect of dSD addition on the changes of the substrate properties as well as the nutrient uptake and the growth of ornamental pot plants such as *Petunia*, *Impatiens* and *Pelargonium*.

MATERIAL AND METHODS

Physical and chemical properties of the components and substrates were analysed according to the European Standards. The growing substrates were analysed for pH (EN 13037:1999; Soils improvers and growing media – determination of pH), electric conductivity (EC) (EN 13038: 1999; Soils improvers and growing media – determination of electrical conductivity) and content of available Ca (EN 13652:2001; Soils improvers and growing media – extraction of water soluble nutrients and elements) in a 1 : 5 (v/v) extract of growing substrate and deionised water. The available contents of other nutrients (N, P, K, Mg, Fe, Mn, Zn, Cu, B, Mo) were determined in a 1 : 5 (v/v) extract of growing substrate and $CaCl_2$/DTPA (CAT method) (EN 13651:2001; Soils improvers and growing media – extraction of calcium chloride/DTPA (CAT) soluble nutrients).

The moisture retention curves were measured in a sand box in the range of –0.25 to –10 kPa of water potential. Preparation and saturation of the growing substrates in standard 5.3 cm high rings were carried out according to EN 13041:1999. Water content was sequentially determined at suction 0.25, 0.5, 1, 2, 3, 5 a 10 kPa till the equilibrium was achieved.

After measurement on the sand box, the sample was oven dried and dry bulk density (DBD) was calculated. The particle density for calculating the total pore space was measured using a pycnometer and total pore space was calculated:

$$PS = (PD - BD) \times 100/PD$$

where: *PS* – total pore space (% volume); *PD* – particle density (kg/m^3); *BD* – bulk density (kg/m^3)

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Table 1. Chemical characteristics (pH, EC, and available macronutrient content, mean, *n* = 3) of pure peat, moist or dry solid phase of digestate (mSD/dSD) and peat based substrates with mSD or dSD in different percent proportions (without addition of fertilizers and limestone)

Treatment	pH	EC (mS/cm)	Available nutrients (mg/l substrate)					
			$N\text{-}NH_4^+$	$N\text{-}NO_3^-$	P	K	Mg	Ca
Peat	4.3	0.05	14	7	1	8	65	13
mSD	9.2	1.01	539	17	154	1,008	138	71
dSD	8.3	1.08	94	10	462	1,536	549	58
mSD20	5.9	0.12	188	4	84	241	26	20
mSD40	6.7	0.23	374	8	118	465	38	25
dSD20	4.8	0.17	35	6	143	340	224	25
dSD40	5.7	0.27	46	7	242	639	269	30
dSD60	6.7	0.28	31	4	215	510	198	28
dSD80	8.3	0.62	103	8	316	1,174	373	44
Peat mixture*	5.5–6.5	0.3–0.5	120–200		40–90	120–180	80–160	50–150
Compost mixture**	5.5–7.3	0.35–0.5	120–200		40–90	120–300	80–160	40–120

optimum for treated organic substrates: *normal range in peat mixtures (Alt 1994); **normal range in compost mixtures (Šrámek, Dubský 2009a); EC – electric conductivity

According to EN 13041:1999 the shrinkage of growing substrates was measured. Results characterize the volume decrease of substrate after drying.

Air pore space and categories of water available to the plants were calculated: air pore space (AS) as the difference between the total pore space and the volume of water at water potential –1 kPa, container (water) capacity (CC) as the volume of water (% volume) at water potential –1 kPa, easily available water (EAW) as the volume of water (% volume) released from the growing substrates when the water potential decreased from –1 to –5 kPa, and water buffering capacity (WBC) as the volume of water (% volume) released from the growing substrates when the water potential decreased from –5 to –10 kPa (de Boodt et al. 1974; Bohne, Wrede 2005), and difficulty available water (DAW) as the volume of water (% volume) at water potential –10 kPa (Prasad, O'Shea 1999).

Moist (mSD) and dry solid phase of digestate (dSD) from agricultural biogas plant were used for preparation of model growing substrates with Baltic milled high bog peat without addition of fertilizers and limestone for adjustment of pH value. Chemical properties of components and model substrates in which the number indicates the proportion (%) of moist (mSDx) or dry (dSDx) solid phase of digestate in volume of peat are provided in Table 1.

The mSD showed alkaline pH and high EC, high content of ammonium nitrogen (>500 mg $N\text{-}NH_4^+$/l), P and K, sufficient content of Ca and Mg, and low content of $N\text{-}NO_3^-$ which correspond with results of Makadi et al. (2012). Raw solid phase of digestate was air-dried at 60°C (i.e. dSD formation) and consequently ammonium nitrogen content significantly decreased, as has been recorded also by Pantelopoulos et al. (2016).

The mSD was applied in amounts of 20 and 40% volume of peat. The dSD was applied in amounts of 20, 40, 60, and 80% volume of peat. In final peat based substrates with mSD with 20% volume there was recorded too high ammonium nitrogen content. The optimal ammonium nitrogen content is approximately 100 mg $N\text{-}NH_4^+$/l in growing substrates. Thus, the optimal dose of SD with natural moistness should be approximately 10% volume of growing substrates. For the pot experiment with partial replacement of peat in growing substrates dSD with elevated rates in which ammonium nitrogen content was not limiting was chosen.

The experiment consisted of five treatments: pure peat substrate (PP, control without addition of dSD), and four peat-based substrates containing 20%, 40%, 60%, and 80% volume of dSD (indicated as dSD20, dSD40, dSD60, and dSD80 respectively). Each treatment with 10 plants altogether was replicated five times. Pre-plant fertilization of PP treatment for all tested plants was carried out using PG Mix fertilizer containing 14% N, 7% P, 15.1%

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K, 0.4% Mg and micronutrients in application dose 1 g/l of substrate. Finely ground limestone, containing 85% $CaCO_3$, 5% $MgCO_3$, was used for adjustment of pH values between pH 5.5–6.0 in control treatment in the application dose 6 g/l of substrate. Substrate for *Petunia* plants was treated by limestone in the rate 3 g/l due to lower pH (5.0–5.5) plant requirement. With regard of separate chemical properties (alkaline pH, high content of available K and P) limestone (1 g/l) was applied only at dSD20 treatment except of *Petunia* substrate. For the substrates with dSD, high in K, P with sufficient amount of micronutrients only nitrogen was applied in the form of calcium nitrate containing 15% N-NO_3^- and 20% Ca. The N rate was decreased with increasing proportion of dSD, dSD20 – 0.6, dSD40 – 0.4, dSD60 – 0.4, dSD80 – 0 g calcium nitrate/l of substrate.

The experiments were established in the greenhouse. Cuttings of pot plants 'Heda' New Guinea *Impatiens*, 'Ville de Paris Rot' *Pelargonium peltatum* and *Petunia* × *hybrid*, clone n. 172 were rooted in a propagation peat-perlite substrate (4 : 1 v/v, pH 5.5). The rooted cuttings were planted at the end of March. We used 10 cm-diameter (400-ml) plastic pots for *Pelargonium* plants and 11-cm-diameter (450-ml) plastic pots for *Impatiens* and *Petunia* plants. The plants were regularly watered with tap water containing 80 mg Ca/l, 20 mg Mg/l and 33 mg S-SO_4/l and uniformly supplementary fertilized. Two weeks after planting, tested plants were fertilized in regular 7–10 day intervals with 2% solution of Kristalon Blue fertilizer containing 19% N, 2.6% P, 16.6% K, and 1.8% Mg. The first supplementary fertilization was not applied for *Impatiens* plants in dSD40 and dSD80 treatments. Overall, supplementary fertilization was applied four times for *Pelargonium* plants and three times for *Impatiens* and *Petunia* plants during vegetation. The *Petunia* plants suffered from chlorosis induced by Fe deficiency at high substrate pH in dSD40, dSD60, and dSD80 treatments. Therefore, the plants in these treatments were treated by solution of chelate Fe-DTPA and Mn-EDTA containing 90 mg Fe and 30 mg Mn per liter of solution twice during vegetation.

The plants were harvested after 6.5 weeks after planting. For *Impatients* plants height, width and average fresh and dry plant weight were determined. For *Pelargonium* and *Petunia* plants only average fresh and dry plant weight were determined. In harvested plant samples nutrient contents in leaves were determined.

Fresh biomass was air-dried at 60°C to total desiccation, dry matter was determined and then plant samples were milled using a ball mill MM 301 (Retsch) and subsequently analysed. The contents of P, K, Ca, Mg, and micronutrients in leaves were determined using inductively coupled plasma-optical emission spectrometry (ICP-OES Trace Scan Advantage, Thermo Jarrell Ash) after microwave digestion appliance (Mileston model MLS 1200) according to their recommended procedure. Total N in leaves was determined by the Kjeldahl method using the SAN Plus System analyzer (Skalar; the Netherlands) after wet-digestion with concentrated H_2SO_4 (98%) and selenium as catalyst.

All data were checked for normality and homogeneity of the variances (Shapiro-Wilk and Leven tests) and then analysed by one-way ANOVA (Unistat 5.2). The significant difference between means were evaluated by Duncan's Multiple Range test at the significance level $P = 0.05$.

RESULTS AND DISCUSSION

Chemical and physical properties of substrates

The application of different rates of fertilizers and limestone into individual treatments (Table 2) partly equilibrated pH values, EC and nutrient contents, but high rates of dSD significantly increased pH and EC values in tested peat based substrates. The pH value in PP and dSD20 treatments ranged from 5.6 to 5.7 respectively, at *Petunia* treatments from 5.0, to 5.1. The other treatments did not receive any lime, but due to growing portion of dSD pH went up to value slightly above 7 at the dSD60 treatment and 8.3 at dSD80 treatment. The optimal concentration of available nutrients, pH and EC values were recorded in dSD20 treatment (Šrámek, Dubský 2009a), and was significantly higher in P, K, Mg, and Zn but lower in N, Cu and Mo compare to treated PP. Instead of pH values there were no differences in PP and dSD20 treatments between *Petunia* and *Pelargonium* substrates.

The concentrations of selected available macronutrients (K, P and Mg) and micronutrients (Mn, Zn and B) were steadily increased in series of dSD40, dSD60, and dSD80 treatments (Tables 2 and 3). The

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Table 2. Chemical characteristics (pH, EC, and available macronutrient content) of treated pure peat (PP) and of peat based substrates with dry solid phase of digestate (dSD) at the beginning of the pot experiment with *Pelargonium* and *Impatiens*

Treatment	pH	EC (mS/cm)	Available macronutrients (mg/l substrate)						
			$N\text{-}NH_4^+$	$N\text{-}NO_3^-$	sum N	P	K	Ca	Mg
PP	5.6[d]	0.32[b]	127[a]	53[ab]	180[a]	64[d]	137[e]	47[a]	169[e]
dSD20	5.7[d]	0.31[b]	53[c]	77[a]	129[b]	116[c]	286[d]	39[ab]	211[d]
dSD40	6.1[c]	0.31[b]	56[c]	31[bc]	86[b]	222[b]	583[c]	31[b]	242[c]
dSD60	7.2[b]	0.56[a]	76[bc]	17[c]	92[b]	337[a]	993[b]	44[a]	334[b]
dSD80	8.3[a]	0.60[a]	97[b]	10[c]	107[b]	343[a]	1,191[a]	46[a]	369[a]

different letters indicate significant differences between treatments (Duncan's test, $P < 0.05$)

Table 3. Chemical characteristics (available micronutrient content) of treated pure peat (PP) and of peat based substrates with dry solid phase of digestate (dSD) at the beginning of the pot experiment

Treatment	Available micronutrients (mg/l substrate)					
	Fe	Mn	Zn	Cu	B	Mo
PP	31.1[a]	4.5[b]	1.7[c]	1.49[a]	0.18[d]	0.105[a]
dSD20	30.8[a]	5.8[ab]	3.4[b]	0.97[b]	0.26[cd]	0.016[b]
dSD40	27.7[ab]	5.7[ab]	4.2[b]	0.85[b]	0.40[bc]	0.006[b]
dSD60	21.9[bc]	5.9[ab]	4.6[ab]	0.80[b]	0.53[b]	0.012[b]
dSD80	19.2[c]	7.5[a]	5.7[a]	0.84[b]	0.74[a]	0.004[b]
Peat mixture*	15–20	3–4	3–4	1.6–1.8	0.2	0.08–0.17
Compost mixture*	34–39	20–26	6–7	1.3–1.6	0.5–0.8	0.02

*normal range of available micronutrients in mixtures (Šrámek, Dubský 2009b); different letters indicate significant differences between treatments (Duncan's test, $P < 0.05$)

concentration of available K considerably exceeded the value of 300 mg K/l in dSD40, dSD60, and dSD80 treatments. It is in accordance with other authors (Carlile 2008; Rainbow 2009) indicating that higher concentration of available K is a limiting factor for using dSD in growing substrates. Concentration of available Zn in dSD treatments was below the range typical for substrates with composts (Šrámek, Dubský 2009b).

Growth of plants affected chemical substrate characteristic at the end of experiment (Table 4). Values of pH corresponded with the initial levels, high rates of dSD significantly increased pH values. The pH values increased at treatments PP and dSD20, at Petunia treatments they were 6.0, resp. 5.6. Concentration of salts (EC) went down only at treatments with dSD60 and dSD80 which could be caused more by the leaching of mobile nitrates and

Table 4. Chemical characteristics of treated pure peat (PP) and of peat based substrates with dry solid phase of digestate (dSD) at the end of the pot experiment with *Pelargonium*

Treatment	pH	EC (mS/cm)	Available nutrients (mg/l substrate)						
			$N\text{-}NH_4^+$	$N\text{-}NO_3^-$	sum N	P	K	Mg	Ca
PP	6.1[c]	0.37[ab]	73[ab]	43[a]	116[ab]	21[e]	75[b]	217[d]	85[a]
dSD20	6.2[c]	0.32[b]	104[a]	18[b]	122[a]	61[d]	82[b]	234[d]	37[b]
dSD40	6.1[c]	0.35[ab]	63[ab]	23[b]	86[abc]	128[c]	216[ab]	286[c]	33[b]
dSD60	7.3[b]	0.42[a]	31[b]	5[c]	36[c]	216[b]	396[a]	369[b]	36[b]
dSD80	8.1[a]	0.42[a]	41[b]	5[c]	46[bc]	326[a]	426[a]	441[a]	34[b]

different letters indicate significant differences between treatments (Duncan's test, $P < 0.05$)

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Table 5. Physical characteristics of treated pure peat (PP) and of peat based substrates with dry solid phase of digestate (dSD) at the beginning of the pot experiment and pure dry solids from digestate (PSD) for comparison

Treatment	BD (g/l)	PD (g/cm³)	P	AS	CC	EAW	WBC	DAW	Shrinkage (%)
			(% volume)						
PP	141[a]	1.56[d]	91.0[f]	13.1[f]	77.9[a]	32.6[a]	8.0[a]	37.3[a]	31.7[a]
dSD20	127[b]	1.58[c]	92.0[e]	20.8[e]	71.2[b]	28.7[b]	6.3[ab]	36.2[a]	32.2[a]
dSD40	108[c]	1.59[c]	93.2[d]	27.8[d]	65.4[c]	26.7c	4.9[bc]	33.8[b]	31.6[a]
dSD60	86[d]	1.60[b]	94.6[c]	40.0[c]	54.6[d]	21.6[d]	3.9[c]	29.1[c]	30.4[ab]
dSD80	79[e]	1.63[a]	95.2[b]	47.5[b]	47.6[e]	17.9[e]	3.1[cd]	26.7[d]	28.4[ab]
PSD	59[f]	1.56[d]	96.2[a]	62.0[a]	34.2[f]	11.3[f]	1.7[e]	21.2[e]	24.0[b]

BD – dry bulk density, PD – particle density, P – porosity, AS – air space, CC – container capacity, EAW – easily available water, WBC – water buffering capacity, DAW – difficultly available water; different letters indicate significant differences between treatments (Duncan's test, $P < 0.05$)

potassium (Möller, Müller 2012). Among studied nutrients both nitrogen forms were the most stable at dSD20 and dSD40 confirming the role of physical properties on N supply and transformations. Because of lower biomass production as well as N content in the substrates dSD60 and dSD80 we can confirm losses of N in these treatments. Content of P and K went down at the end of experiment at all treatments; the final substrate content corresponded with applied amount and grew up with the rate of dSD. Only Mg showed growth in the substrate at the end of experiment, which could be caused by lower Mg uptake by plants compare to other nutrients (Verlinden 2003) and higher Mg content in tap water.

Addition of dSD affected also physical properties of peat based substrates (Table 5). Majority of substrate properties was changed in the SD treatments. The BD, CC, EAW, and DAW went down showing less available water present for plants, but PD, P, and AS went up with the growing portion of dSD in the substrate and in comparison to the PP treatment. Significantly higher air space (AS), lower content of difficulty available water (DAW) and thus lower total water capacity of dSD60 and dSD80 growing substrates in comparison to the PP treatment. Therefore, from the viewpoint of the physical properties the dSD20 and dSD40 treatments are the most suitable for plant growth. Growing substrates in these treatments can be included among substrates with higher air space (AS) characterized by 20–30% volume and EAW >20% volume (Verdonck et al. 1983).

Biomass production and tissue analysis

The highest biomass production of all three tested plants was recorded in PP treatment in fresh as well in dry biomass. The elevated amount of dSD addition into peat showed adverse effect on the growth of plants. Comparable biomass of flowers with PP treatment was also found at dSD20 treatment (Table 6). The *Impatiens* and *Pelargonium* plants were

Table 6. Biomass production of tested plants at the end of the pot experiment

Treatment	*Pelargonium*		*Petunia*		*Impatiens*			
	fw (g)	dw (g)	fw (g)	dw (g)	fw (g)	dw (g)	height (cm)	width (cm)
PP	76.0[a]	6.9[a]	41.1[a]	3.9[a]	58.0[a]	4.3[a]	8.6[b]	24.2[a]
dSD20	67.1[ab]	6.0[b]	29.4[b]	3.0[b]	47.6[ab]	3.3[b]	8.7[b]	23.3[a]
dSD40	62.9[b]	5.7[b]	26.0[b]	2.8[b]	50.5[ab]	3.5[b]	9.5[a]	23.2[a]
dSD60	48.8[c]	4.7[c]	16.5[c]	1.6[c]	39.9[c]	2.8[c]	7.9[b]	19.8[b]
dSD80	38.8[d]	3.8[d]	6.8[d]	0.8[d]	–	–	–	–

fw – plant fresh weight, dw – plant dry weight; different letters indicate significant differences between treatments (Duncan's test, $P < 0.05$)

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Table 7. Foliar content of macronutrients (%) and micronutrients (mg/kg)

Treatment	Dry weight basis (%)					Dry weight basis (mg/kg)					
	N	P	K	Ca	Mg	Fe	Mn	Zn	Cu	B	Mo
Pelargonium											
PP	2.70^{a}	0.53^{a}	2.55^{d}	1.20^{a}	0.25^{b}	79.3^{a}	128.4^{a}	38.6^{a}	4.9^{a}	34.8^{a}	3.65^{a}
dSD20	2.69^{a}	0.47^{a}	2.45^{d}	1.07^{a}	0.27^{b}	78.6^{a}	98.2^{b}	33.4^{bc}	1.2^{d}	25.0^{c}	0.43^{b}
dSD40	2.76^{a}	0.52^{a}	3.22^{c}	0.82^{b}	0.32^{a}	74.8^{a}	38.7^{c}	35.9^{ab}	2.2^{c}	35.1^{a}	0.39^{b}
dSD60	2.61^{a}	0.48^{a}	3.63^{b}	0.60^{c}	0.27^{b}	55.8^{b}	31.8^{c}	30.5^{c}	3.9^{b}	32.6^{a}	0.59^{b}
dSD80	2.58^{a}	0.40^{b}	4.71^{a}	0.41^{d}	0.24^{b}	42.1^{c}	13.7^{d}	21.5^{d}	4.5^{ab}	28.9^{b}	0.55^{b}
Normal range**	3.3–4.8	0.40–0.67	2.5–4.5	0.80–1.20	0.20–0.52	70–268	42–174	30–280	7–16	8,0–40	0.2–5
Impatiens											
PP	4.25^{a}	0.48^{b}	1.69^{b}	2.31^{a}	0.67^{a}	139.9^{a}	50.9^{a}	71.2^{a}	4.3^{a}	29.5^{b}	5.80^{a}
dSD20	4.15^{a}	0.56^{ab}	1.88^{b}	1.86^{b}	0.63^{a}	79.1^{b}	20.6^{b}	68.3^{a}	4.4^{a}	31.0^{b}	0.37^{c}
dSD40	4.13^{a}	0.59^{a}	3.08^{a}	1.12^{c}	0.63^{a}	64.9^{b}	34.7^{b}	56.2^{b}	6.1^{a}	40.5^{a}	1.61^{b}
dSD60	4.09^{a}	0.61^{a}	3.74^{a}	0.68^{d}	0.62^{a}	53.8^{b}	31.7^{b}	50.9^{b}	5.0^{a}	38.3^{ab}	2.88^{b}
Normal range*	2–4.5	0.2–0.8	1.5–4.5	0.5–2.0	0.3–0.8	75–300	50–250	25–100	5–15	20–60	0.2–5
Petunia											
PP	3.76^{a}	0.94^{b}	5.39^{b}	0.74^{a}	0.38^{a}	129.3^{d}	70.5^{a}	40.8^{b}	14.1^{b}	9,2^{b}	0.46^{bc}
dSD20	3.63^{ab}	0.99^{b}	4.99^{b}	0.66^{a}	0.36^{a}	171.7^{cd}	62.8^{a}	43.0^{b}	12.9^{b}	7.0^{b}	0.15^{d}
dSD40	3.50^{bc}	1.22^{a}	6.88^{a}	0.46^{b}	0.30^{b}	255.4^{a}	68.7^{a}	57.5^{a}	3.3^{c}	6.2^{b}	0.29^{cd}
dSD60	3.73^{a}	1.24^{a}	7.31^{a}	0.35^{b}	0.24^{c}	228.2^{ab}	48.9^{b}	33.9^{bc}	5.1^{c}	5.6^{b}	0.53^{b}
dSD80	3.40^{c}	0.50^{c}	6.63^{a}	0.19^{c}	0.12^{d}	190.6^{bc}	25.7^{c}	27.8^{c}	21.4^{a}	17.0^{a}	0.98^{a}
Normal range*	4–7.6	0.5–0.9	3.1–6.7	1.2–2.8	0.4–1.4	85–170	45–177	33–85	3–19	18–43	0.2–5

*normal range of nutrients for *Impatiens* and *Petunia* plants (Mills, Jones 1996); ** normal range of nutrients for *Pelargonium* plants (Vetanovetz 1996); different letters indicate significant differences between treatments within the species (Duncan's test, $P < 0.05$).

produced in sufficient market quality in dSD40 treatment as well. The biomass production was substantially decreased in dSD60 and dSD80 treatments because of higher pH value for *Petunia* plants (Smith et al. 2004) and of higher content of soluble salts for *Impatiens* plants (Judd, Cox 1992). The EC = 0.6 mS/cm was too high for *Impatients* plants at the beginning of the experiment at dSD80 treatment, therefore the plants died ten days after planting.

Content of macronutrients as well as micronutrients differed according to plant species and treatment of experiment. Accumulation pattern was not clear enough and individual species showed specific accumulation ability to individual elements (Table 7).

The decreasing rate of N from fertilizers with growing portion of dSD in the substrate showed no significant effect in N content in tissues of all growing plants. Accumulation of P was shown in *Impatiens and Petunia* plants and P reduction in *Pelargonium* tissues with growing rates of dSD in the substrates, without clear effect of elevated P rates by dSD. The increasing proportion of dSD in peat based substrates significantly increased content of K and decreased content of Ca in tested plants and also of Mg only in *Petunia* plants (Table 7). The foliar content of K was higher than normal range for plants (i.e. > 6.7%; Mills, Jones 1996), mainly for *Petunia* plants, in dSD40, dSD60, and dSD80 treatments. It was connected with higher concentration of available K in dSD-peat substrates and also with lower biomass production caused by higher pH value of substrates. Higher foliar K content decreased foliar Ca content for all tested plants and also foliar Mg content but mainly for *Petunia* plants due to antagonism among these nutrients.

Lower foliar Fe and Mn contents were recorded in treatments with growing rates of dSD. Supplementary fertilization of *Petunia* plants with chelate Fe-DTPA and Mn-EDTA solutions alleviated chlorosis during vegetation and increased foliar Fe content in dSD40, dSD60, and dSD80 treatments. Nevertheless, chlorosis limited biomass production in

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dSD60 and dSD80 treatments. The increased pH values of the substrates played more important role in Fe and Mn uptake than growing amount of both nutrients coming with dSD.

CONCLUSION

Solid phase of digestate (SD) from agricultural biogas plants is suitable for production of growing substrates up to some extent. The SD of agricultural biogas plants is slightly alkaline characterised by approximately 20% of dry matter content and high available contents of N-NH_4^+ and K. Contents of these nutrients in moist SD were limited for preparation of peat based substrates with SD. Drying of SD significantly decreased N-NH_4^+ content, therefore it is possible to use higher doses of dSD in peat based substrates. Peat based substrates with 20% volume of dSD are optimal mixtures with respect to the physico-chemical properties of mixtures and nutrient uptake by plants. For plants demanding nutrients at larger extent it is possible to use higher rate of dSD up to 40% of peat based substrates. The fertilization of dSD-peat substrate has to respect contents of macro and micronutrients. Plants growth in dSD20 treatment was comparable with control PP treatment. Nutrients uptake mainly depended on pH value of dSD-peat substrates and in the case of K on the content in the substrate too. Foliar content of K was increased and of Ca was decreased with increasing rate of dSD in the peat based substrates. Content of microelements in plants, mainly Fe and Mn, decreased with increasing pH value of substrate. Plant growth was also affected by physical properties of dSD-peat substrates. The lower easily available water content of dSD-peat substrates produced more compacted plants at dSD20 and dSD40 treatments in comparison to PP treatment.

References

Abubaker J., Risberg K., Pell M. (2012): Biogas residues as fertilisers – effects on wheat growth and soil microbial activities. Applied Energy, 99: 126–134.

Alt D. (1994): Eine neue rationelle Analysen-Methode. Deutscher Gartenbau, 48: 205–207.

Bohne H., Wrede A. (2005): Investigations of physical properties of growing substrates. European Journal of Horticultural Science, 70: 1–6.

Bustamante M.A., Restrepo A.P., Alburquerque J.A., Pérez-Murcia M.D., Paredes C., Moral R., Bernal M.P. (2013): Recycling of anaerobic digestates by composting: effect of the bulking agent used. Journal of Cleaner Production, 47: 61–69.

Carlile W.R. (2008): The use of composted materials in growing media. Acta Horticulturae (ISHS), 779: 321–327.

Crippa L., Zaccheo P., Orfeo D. (2013): Utilization of the solid fraction of digestate from anaerobic digestion as container media substrate. Acta Horticulturae (ISHS), 1013: 367–373.

de Boodt M., Verdonck O., Cappaert I. (1974): Method for measuring water release curve of organic substrates. Acta Horticulturae (ISHS), 37: 254–262.

Fisher P.R. (2004): Managing pH for container media. In: Hamrick D. (ed.): Ball RedBook. Batavia, Ball Publishing: 39–45.

Judd L.K., Cox D.A. (1992): Growth of New Guinea Impatiens inhibited by high growth-medium electrical conductivity, Hortscience, 27: 1193–1194.

Makadi M., Tomocsik A., Orosz V. (2012): Digestate: a new nutrient source – Review. In: Kumar S. (ed.): Biogas. Rijeka, InTech: 295–309.

Mills H.A., Jones J.B. (1996): Plant Analysis Handbook II. Athens, MicroMacro Publishing Inc.

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.

Pantelopoulos A., Magid J., Jensen L.S. (2016): Thermal drying of the solid fraction from biogas digestate: effects of acidification, temperature and ventilation on nitrogen content. Waste Management, 48: 218–226.

Prasad M., O´Shea J. (1999): Relative breakdown of peat and non-peat growing media. Acta Horticulturae (ISHS), 481: 121–128.

Rainbow A. (2009): The use of green compost in the production of container nursery stock in the UK: challenges and opportunities. Acta Horticulturae (ISHS), 819: 27–32.

Restrepo A.P., Medina E., Pérez-Espinosa A., Agulló E., Bustamante M.A., Mininni C., Bernal M.P., Moral R. (2008): Substitution of peat in horticultural seedlings: suitability of digestate-derived compost from cattle manure and maize silage codigestion. Communications in Soil Science and Plant Analysis, 44: 668–677.

Schmilewski G. (2008): The role of peat in assuring the quality of growing media. Mires and Peat, 3: 1–8.

Smith B.R., Fisher P.R., Argo W.R. (2004): Growth and pigment content of container-grown impatiens and petunia in relation to root substrate pH and applied micronutrient concentration. Hortscience, 39: 1421–1425.

Sonneveld C., Voogt W. (2009): Plant nutrition of greenhouse crops. Netherlands, Springer Netherlands.

Šrámek F., Dubský M. (2009a): Peat substrates amended with composted bark or with compost. Acta Horticulturae (ISHS), 819: 387–394.

https://doi.org/10.17221/221/2016-HORTSCI

Šrámek F., Dubský M. (2009b): Occurrence and correction of chlorosis in young petunia plants. Horticultural Science (Prague), 36: 147–153.

Torres-Climent A., Martin-Mata J., Marhuenda-Egea F., Moral R., Barber X., Perez-Murcia M.D., Paredes C. (2015): Composting of the solid phase of digestate from biogas production: optimization of the moisture, C/N ratio, and pH conditions. Communications in Soil Science and Plant Analysis, 46: 197–207.

Verdonck O., Penninck R., de Boodt M. (1983): The physical properties of different horticultural growing substrates. Acta Horticulturae (ISHS), 150: 155–160.

Verlinden S. (2003): Changes in mineral nutrient concentrations in petunia corollas during development and senescence. Hortscience, 38: 71–74. Vetanovetz R.P. (1996): Tissue analysis and interpretation. In: Reed D.W. (ed.): Water, media, and nutrition for greenhouse crops. Batavia, Ball Publishing: 197–220.

Weiland P. (2010): Biogas production: current state and perspectives. Applied Microbiology and Biotechnology, 85: 849–860.

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