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Biogas-digestate as nutrient source for biomass production of *Sida hermaphrodita*, *Zea mays* L. and *Medicago sativa* L.

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Abstract

A sustainable management of the residues from biogas plants has to be considered due its potential use as plant fertilizer and soil conditioner. Our objective was to evaluate the biogas-digestate as a nutrient source for biomass production of three different plants: sida (*Sida hermaphrodita* – Malvaceae), maize (*Zea mays* L. – Poaceae) and alfalfa (*Medicago sativa* L. - Fabaceae). The used biogas-digestate was obtained after the anaerobic digestion of maize silage, as the major feedstock, and minor amounts of chicken manure. The treatments were established in five replicates including biogas-digestate, NPK fertilizer and a control. Pots were filled with the fertilized soils (biogas-digestate and NPK treatments) and control soil, and seedlings were transplanted and grown for 30 days under greenhouse conditions. Analysis of the shoot and root dry mass and nutrients content (C, N and P) of *Sida hermaphrodita*, *Zea mays* L. and *Medicago sativa* L. revealed similar values for both biogas-digestate and the NPK fertilizer applications, which were greater than the control, showing a positive fertilizing effect of the biogas-digestate for biomass production of the respective plants.

Keywords: residue; fertilization; energy crops; nutrients cycling.

1. Introduction

The use and increase of renewable energy sources are supported in many countries driven by climate and energy policies. The energy production from renewable sources in the European Union should reach 20% by 2020 [1]. In

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Germany, the renewable energy consumption reached 11.6%, which was mainly based on energy conversion from biomass (8.2%) [2]. Germany is the largest biogas producer in the European Union with more than 7,515 biogas plants in 2012 [2,3]. A sustainable resource management has to be considered within this growing scenario of biogas production systems, especially due its potential for a closed nutrient cycle. The recycling of nutrients present in the residues resulting from biogas production, the so called digestates, can be promoted with the application of the residues as fertilizers [4]. The application of biogas-digestate as organic fertilizers can increase the aboveground N uptake and biomass yield [5,6] and improve soil physical properties in terms of lower bulk density, higher hydraulic conductivity and greater moisture retention of soil [7].

Maize (*Zea mays* L. (Poaceae)) silage is the major feedstock (73%) for biogas production in Germany [2]. Biogas production with maize is due to its dry matter (13 to 23 t ha^{-1}) and biogas yields (200 Nm^3 t^{-1} fresh matter), besides the optimized production techniques and existing infrastructure [2,3]. Maize is often grown in monoculture systems [8]. However, studies recommend as sustainable practice growing maize in extended rotations including forage legumes due to their potential to increase soil N levels [9]. Alfalfa (*Medicago sativa* L. (Fabaceae)), like other legumes, presents root nodules containing bacteria able to fix N, thus increasing nitrogen availability to subsequent crops [10]. As presented earlier, a bio refinery-based crop rotation system including wheat (*Triticum aestivum* L.), *Zea mays* L., barley (*Hordeum vulgare* L.), sunflower (*Helianthus annuus* L.), *Medicago sativa* L., and sorghum (*Sorghum bicolor* L.) produced higher energy and biomass yields than under monocultures [11].

The exploitation of non-food biomass for energy production is required to avoid conflicts with food and fuel uses. Sida (*Sida hermaphrodita* (Malvaceae)) is a rather unknown perennial plant native to the North America, but it has becoming more popular due its high biomass yields for energy production [12]. Sida has low requirements to the soil conditions, and depending on the field conditions and cultivation practices produces 12 to 20 t ha^{-1} of dry matter from its second year of cultivation [12,13]. An ecological benefit for sida is the ability to store carbon in its highly developed root system, and consequently, keeping it underground sequestered for many years [14]. Another important aspect is the moisture content at harvest time, since sida is characterized by the drying up of shoots at the end of the growing season and the winter harvesting [13].

The present work evaluated the biomass production of *Sida hermaphrodita*, *Zea mays* L. and *Medicago sativa* L. grown in the presence of biogas-digestate applied as a fertilizer. These three species were chosen because of their high biomass yield and current importance as a feedstock or co-ferment for biogas production (*Zea mays* L.); the N-fixing properties to improve soil fertility (*Medicago sativa* L.); and a perennial crop with potential for an alternative biogas feedstock (*Sida hermaphrodita*). Within the agricultural scenario, crop rotation systems are considered the basis for a sustainable production of biomass as well as for soil productivity [8,10]. Integrating energy crops and sustainable crop rotation systems can lead to both environmental and agricultural benefits with regard to soil properties and nutrient cycling. Studies on promising perennial non-food energy plants and the use of biogas-digestate as a fertilizer are needed and are part of our research at the IBG:2 Plant Sciences, Research Centre Jülich.

2. Material and Methods

2.1. Biogas-digestate and soil

Table 1 shows the biogas-digestate and soil element composition at the beginning of the experiment, which were measured via ICP-OES. The biogas-digestate was collected from an operating biogas facility (fermenter volume 2500 m³, ADRW Natur Power GmbH & Co. Kg Ameln, Germany) composed of maize silage as the major feedstock, and minor amounts of chicken manure. An arable field soil (Endogleyic Stagnosol) was collected from 0–30 cm depth and 5 mm sieved.

Table 1: Biogas-digestate and soil element composition at the beginning of the experiment.

	pH	C (%)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	S (%)	Al (%)	Na (%)	Cu (%)	Mn (%)	Mo (%)	Zn (%)
Biogas-digestate	8.35	41.10	3.20	1.50	3.75	3.21	0.57	0.39	0.09	0.15	<0.01	0.03	<0.01	0.03
Soil	6.31	1.06	0.11	0.12	1.65	0.450	0.29	0.02	3.88	0.61	<0.01	0.08	<0.01	<0.01

2.2. Experimental conditions

A greenhouse pot experiment was established at the IBG:2 Plant Sciences, Research Centre Jülich (location: 50.89942°N 6.39211°E). The experiment was performed in a completely randomized design and the treatments applied in five replicates were: 1. biogas-digestate (Table 1) with an equivalent field application dose of 40 t ha^{-1}, 2. mineral NPK fertilizer (Scotts Australia PTY Ltd; N:15%, P: 4.5%; K: 24.1%) with an application amount equivalent to 200–100–300 kg ha^{-1}, according to the recommended agricultural doses, 3. untreated control.

The biogas-digestate and the NPK fertilizer were thoroughly mixed with the soil in a rotatory mixer for 30 min. Pots with dimensions of 11cm x 11cm x 12cm were filled with the biogas-digestate, NPK fertilizer and control soils. Seedlings of *Sida hermaphrodita*, *Zea mays* L. and *Medicago sativa* L. were transplanted, keeping one seedling per pot. Plants were grown under controlled conditions of 16h per day of light period (natural day light in combination with an automated light system with sodium-vapour lamps [SON-T AGRO 400, Phillips] ensuring a minimum irradiance of 400µmol s^{-1} m^2), day/night temperature of 22°C/17°C and a constant humidity of 60%. Plants were watered continuously by an automated irrigation system, and water was allowed to drain from the pots through holes in the bottom. All pots were re-randomized twice during the experimental period to minimize the effect of spatial environmental variation.

At 30 days after start of the treatments, plants were cut at ground level and divided into roots and shoots. Roots were manually washed, and subsequently, roots and shoots were dried to constant weight (70ºC for 48 h). Root and shoot mass fractions were calculated as the fraction of root and shoot mass with respect to total dry mass. The response variables measured were root and shoot dry mass and C, N and P biomass contents. The analysis of variance (ANOVA) and the mean comparison (Tukey's test, $p < 0.05$) of the biomass (root and shoot) were performed using the Statistical Analysis System (SAS) 9.3.

3. Results and Discussion

Figure 1 presents the shoot and root dry mass of *Sida hermaphrodita*, *Zea mays* L. and *Medicago sativa* L. plants obtained after the biogas-digestate, NPK fertilizer and control treatments. *Zea mays* L. showed the highest shoot and root mass, followed by *Sida hermaphrodita* and *Medicago sativa* L. The shoot biomass of *Sida hermaphrodita*, *Zea mays* L. and *Medicago sativa* L. obtained after the biogas-digestate and the NPK fertilizer treatments were greater than the control, and no statistical difference was observed for root biomass among the treatments.

Plants have to balance the allocation to leaves, stems and roots to match the physiological activities and functions performed by these organs. Changes in allocation pattern are mainly due to light, nutrients and water supply and atmospheric CO_2 concentration. Below-ground conditions as low availability of either water or nutrients are expected to increase root biomass [15]. Our findings show similar biomass allocation pattern among treatments with a greater proportion of biomass allocated to shoot than to root. The shoot mass fraction (g g^{-1}) varied from 0.68 to 0.71 for *Sida hermaphrodita*, from 0.80 to 0.85 for *Zea mays* L., and from 0.83 to 0.84 for *Medicago sativa* L. The greatest shoot mass allocation can be explained by the supply of water and nutrients during the experimental period.

A two-year field experiment determined the potential of biogas residue in crop yield concluded that the residue could be effectively used in the short term to provide nutrients to crops [16]. The authors reported no significant differences in the cumulative plant dry mass of *Medicago sativa* L. subjected to anaerobic digestates and mineral fertilizers, whereas for cocksfoot grasses mean yield was higher in plots treated with biogas residue in relation to control plots. These findings are in accordance with our results, since no significant differences were observed in the dry mass of *Sida hermaphrodita*, *Zea mays* L. and *Medicago sativa* L. between the biogas-digestate and NPK fertilizer treatments.

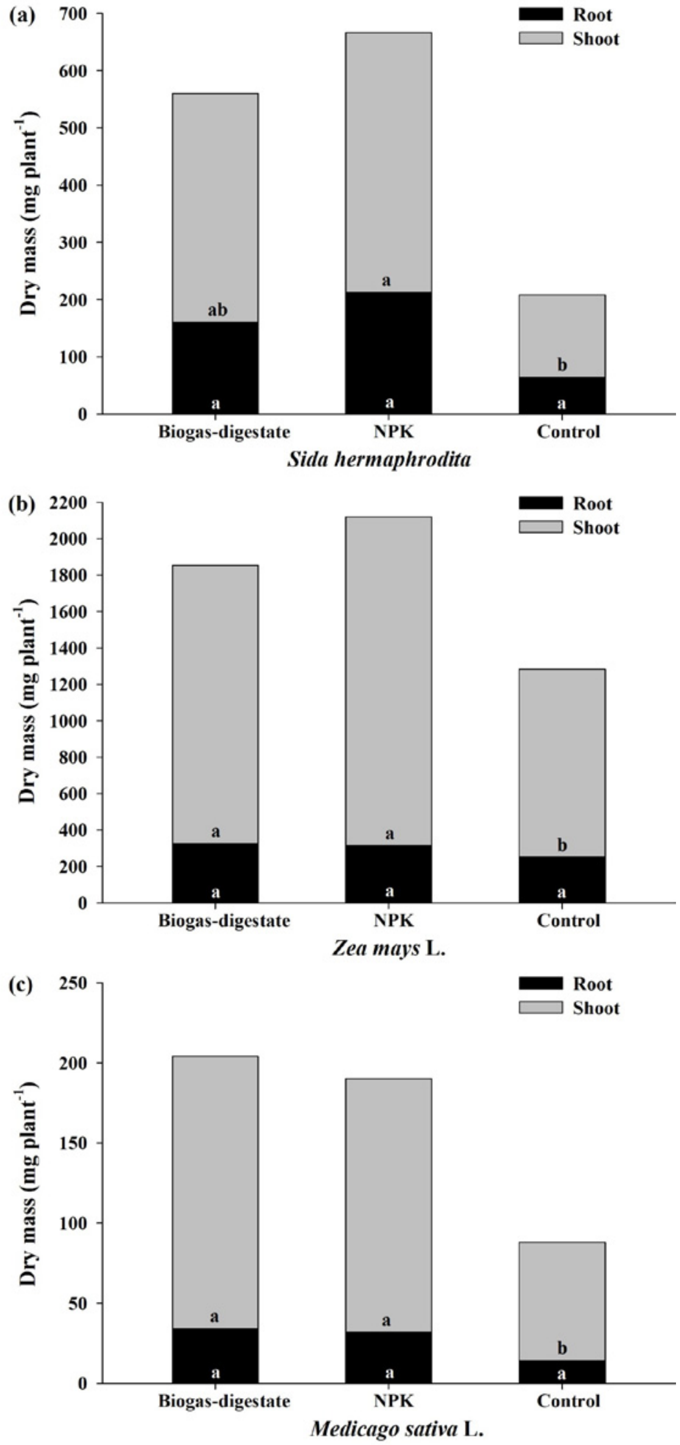

Fig 1. Dry mass (mg plant^{-1}) of *Sida hermaphrodita* (a), *Zea mays* L. (b) and *Medicago sativa* L. (c) plants obtained after the treatments. (The minimum significant differences ($p < 0.05$) were: for *Sida hermaprhodita* – shoot: 301.82 and root: 182.47; for *Zea mays* L. – shoot: 397.46 and root: 134.31; for *Medicago sativa* L. – shoot: 83.89 and root: 27.01).

Table 2 presents the C, N and P (mg g^{-1}) contents and the C:N and N:P ratios of shoot and root of *Sida hermaphrodita*, *Zea mays* L. and *Medicago sativa* L. plants obtained after the biogas-digestate, NPK fertilizer and control treatments. For *Sida hermaphrodita* and *Zea mays* L. the highest values of nutrients content (mg of C, N and P g^{-1}) were mainly obtained for the NPK fertilizer treatment, followed by the biogas-digestate treatment, with exception of P content in *Zea mays* L. For *Medicago sativa* L. the highest values were obtained for the biogas-digestate treatment. Leaf nutrient concentrations, mainly N and P, are important determinants of growth potential [17]. Our findings showed higher N, P and C contents in shoot than roots for *Sida hermaphrodita*, *Zea mays* L. and *Medicago sativa* L.

The C:N:P stoichiometry of terrestrial plants is determined by the balance of nutrient uptake for growth and it can also be influenced by nutrient supply [17,18]. The C, N and P concentrations of some shrub and herbaceous plants were previously reported in a range of 285.5 to 406.8 mg g^{-1} for C, of 15.3 to 70.8 mg g^{-1} for N, and of 5.8 to 19.9 mg g^{-1} for P. Further, the N:C and N:P ratios varied between 0.04 and 0.21, and 1.46 and 9.27, respectively. The authors stated the whole-plant N and P concentrations were on average higher than the values reported for leaves of terrestrial species [18]. Comparing to our findings, the C, N and P contents of *Sida hermaphrodita*, *Zea mays* L. and *Medicago sativa* L. plants after the treatments varied from 140.8 to 515.4 mg g^{-1} for C, from 9.9 to 42.8 mg g^{-1} for N, and from 1.5 to 5.7 mg g^{-1} for P. The C:N and N:P ratios ranged between 10 and 33, and 4 and 15, respectively. Thus, differences in the C:N:P stoichiometry can be explained by the characteristics of each species and also by the availability of nutrients within the treatments.

Table 2. C, N and P content (mg g^{-1}) and C:N and N:P ratios of shoot and root of *Sida hermaphrodita*, *Zea mays* L. and *Medicago sativa* L. plants obtained after the treatments.

	C (mg g^{-1})		N (mg g^{-1})		P (mg g^{-1})		C:N		N:P	
Treatments	Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root	Shoot	Root
					Sida hermaphrodita					
Digestate	396.0	400.0	37.1	23.5	3.5	2.9	11	17	11	8
NPK	458.5	515.4	42.8	34.2	3.4	5.6	11	15	13	6
Control	140.8	159.6	11.1	10.1	1.9	1.8	13	16	6	6
					Zea mays L.					
Digestate	425.0	414.0	20.1	12.4	2.7	2.0	21	33	7	6
NPK	502.3	405.1	21.5	14.2	3.9	2.4	23	28	6	6
Control	281.6	330.6	10.9	9.9	3.0	2.7	26	33	4	4
					Medicago sativa L.					
Digestate	430.0	402.0	38.3	37.7	3.1	5.7	11	11	12	7
NPK	391.3	372.7	37.6	35.2	2.5	5.1	10	11	15	7
Control	179.8	163.5	17.4	13.8	1.5	1.9	10	12	11	7

The anaerobic digestion procedure in biogas plants basically degrade the organic fractions of feedstock to CH_4, CO_2 and digested residues, conserving N mainly as NH_4^+. Essential nutrients as N, P, K, Mg, and some trace elements required by plants are conserved in the residue and thus enhancing crop yield when used as a fertilizer in plant production [4,5]. The presence of important nutrients in the biogas-digestate applied in our study also led to a positive fertilizing effect for the plants.

The biogas-digestate applied in our study showed an C:N ratio of 12.8 (Table 1) which is greater than other biogas residues used in previous studies [19,20]. Different composition of the main feedstock and conditions of the biogas plant reactors, mainly temperature and retention times, resulted in biogas residues with C:N ratios which varied from 4.2 to 12.1 [19,20]. Besides the low C:N ratio in biogas residues compared to raw and untreated material, in general, biogas residues present an efficient N source for the fertilization of agricultural crops [4]. The evaluation of how effectively biogas-digestate can substitute or reduce the use of mineral fertilizers in terms of crop yield is of particular interest. However, it is important to monitor the quality of biogas-digestate before its application taking into account the different crop needs and soil conditions.

4. Conclusion

The applied biogas-digestate in our study presented an effective potential as plant fertilizer since its effect was similar to the NPK fertilizer regarding the biomass production of *Sida hermaphrodita*, *Zea mays* L. and *Medicago sativa* L. and its nutrients (C, N and P) content. More extensive studies are needed to evaluate the use of biogas-digestate as fertilizer and soil conditioner, including important aspects as leaching of mineralized N and other nutrients into deeper soil layers, as well as biogas-digestate influences on the soil C pool and C turnover.

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