USE OF DRY AND WET DIGESTATES FROM BIOGAS PLANTS AS FERTILIZER IN PLANT PRODUCTION

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1 INTRODUCTION

An important product of anaerobic digestion is a mixed gas primarily composed of methane and carbon dioxide, which is commonly called biogas (Ebenezer et al., 2007). In the EU the biggest amount of biogas comes from landfills, but in Germany it is mainly agricultural waste from which biogas is produced (Biogas Barometer, 2008). This digestate contains reduced amounts of dry matter and total organic carbon and increased NH_4^+-N concentrations and pH values (Ernst et al., 2007). Annually, millions of tonnes of digestate are used as fertilizers in crop production in order to close the nutrient cycle in agricultural ecosystems. However, the effects of these fertilizers on soil conditions and crop yields, especially from an ecological point of view, are not completely understood. Therefore, the influence of dry and wet digestate applications to different crops, on yields and soil conditions were studied within this project.

2 MATERIALS AND METHODS

The effect of dry and wet digestates applied as organic fertilizers were compared with conventional fertilizers in on-farm and field experiments.

The on-farm experiments were carried out in two different German agricultural companies. The first company produces biogas through a wet fermentation from cattle manure, silage maize, silage grass, and millet. A residual product the so called wet digestate, a pumpable, homogeneous, and semi-liquid residue, is obtained. The second company produces biogas through a dry fermentation from silage maize. The residual product is a dry digestate which contains up to 70% of water. In the on-farm experiments, different amounts of wet and dry digestates produced by the respective companies and a combination with mineral fertilizers were applied at two different times (spring and autumn). In the field of the first company winter rye was sown as experimental crop in a loamy sand soil. In the field of the second one, winter wheat was sown in a silty clay soil.

Furthermore, to investigate the effect of wet and dry digestates in direct comparison to conventional fertilizers such as mineral fertilizer (Calcium ammonium nitrate), liquid manure, and farmyard manure, a field experiment was carried out within a randomised complete block design. In this experiment an amount of fertilizer corresponding to 120 kg N ha^{-1} for each variant was applied, therefore the amounts of the organic and mineral fertilizers varied according to their nitrogen content. The corresponding amount of fertilizers were 25,81 t ha^{-1} fresh weight (FW) (7,95% DM) for wet digestate, 22,43 t ha^{-1}FW (17,04% DM) for dry disgestate, 27,71 t ha^{-1} FW (9,86% DM) for liquid manure and 16,64 t ha^{-1} FW (28,63% DM) for farmyard manure. An untreated control was used as a reference. As experimental crop *Sorghum bicolor* var. *sudanense* was sown in a loamy sand soil. Among other parameters, the dry matter yield (grain + straw) and the grain yield were measured after each harvest.

Also, an assessment of the impact of wet and dry digestates on earthworm population in comparison to conventional organic fertilizers and the untreated control was carried out. To obtain information about the earthworm population distribution between the different fertilizer treatments, hand sorting of a soil core with 0.125 m² and 20 cm depth was combined with the formalin extraction to collect the species corresponding to a vertically stratified distribution.

3 RESULTS

3.1 On-Farm Experiments

On the loamy sand soil, the highest winter rye yield was achieved with 120 kg N ha^{-1} applied in a single dose of mineral fertilizer in spring (MF2). An application of 120 kg N ha^{-1}, applied as a combination of 80 kg N ha^{-1} of wet digestate in autumn and 40 kg N ha^{-1} mineral fertilizer in spring (WD3), resulted in a comparable grain yield to the mineral fertilization of 120 kg N ha^{-1} applied in spring in a single dose (Table 1, Fig. 1).

TABLE 1 **Different combinations of wet digestate (WD) and mineral fertilizers (MF) given at two application times.**

Treatment	Autumn (kg N ha^{-1})	Fertilizer	Spring (kg N ha^{-1})	Fertilizer	Total (kg N ha^{-1})
WD 1	40	Wet Digestate	80	Mineral	120
WD 2	80	Wet Digestate	0	--	80
WD 3	80	Wet Digestate	40	Mineral	120
WD 4	0	--	80	Wet Digestate	80
WD 5	0	--	80/40	Wet Digestate/Mineral	120
Control	0	--	0	--	0
MF 1	0	--	80	Mineral	80
MF 2	0	--	120	Mineral	120
MF 3	40	Mineral	40	Mineral	80
MF 4	80	Mineral	40	Mineral	120

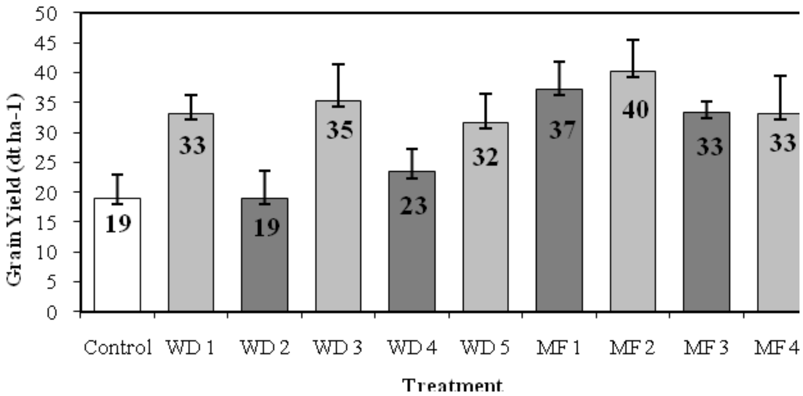

FIGURE 1 **Grain yield (dt ha^{-1} by 86% Dry Matter Content) of winter rye related to table 1**. Mean Value and Standard Error. Dark grey correspond to 80 kg N ha^{-1}. Light grey correspond to 120 kg N ha^{-1}.

On the silty clay soil, the highest grain yield of winter wheat was observed using a combination of 50 kg N ha^{-1} mineral fertilizer in autumn and 100 kg N ha^{-1} mineral fertilizer in spring (MF3). Similar results were observed using a combination of 100 kg N ha^{-1} dry digestate in autumn and 50 kg N ha^{-1} dry digestate in spring (DD2) (Table 2, Fig. 2).

TABLE 2 **Different combinations of dry digestate (DD) and mineral fertilizers (MF) given in two application times.**

Treatment	Autum (kg N ha^{-1})	Fertilizer	Spring (kg N ha^{-1})	Fertilizer	Total (kg N ha^{-1})
Control	0	--	0	--	0
DD 1	75	Dry Digestate	25	Dry Digestate	100
DD 2	100	Dry Digestate	50	Dry Digestate	150
DD 3	150	Dry Digestate	0	--	150
MF 1	0	--	100	Mineral	100
MF 2	50	Mineral	100	Mineral	150
MF 3	0	--	150	Mineral	150

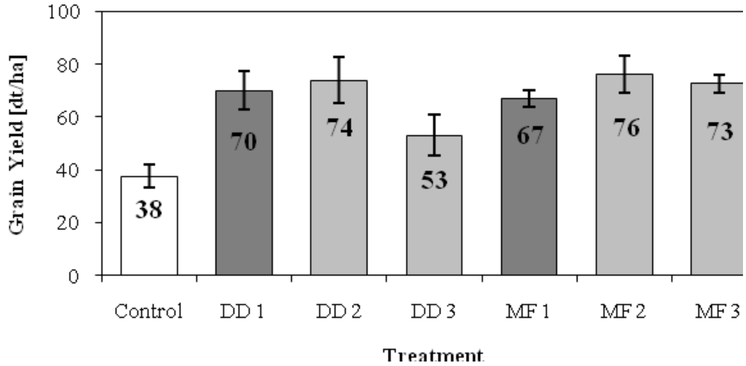

FIGURE 2 **Grain yield (dt ha^{-1} by 86% Dry Matter Content) of winter wheat related to table 2**. Mean Value and Standard Error. Dark grey correspond to 100 kg N ha^{-1}. Light grey correspond to150 kg N ha^{-1}.

3.2 Field Experiments

The results showed that on a loamy sand soil, when applying the same amount of nitrogen for each treatment (120 kg N ha^{-1}), the mineral fertilizer had a significantly positive effect on the dry matter yield of *Sorghum bicolor* var. *sudanense* as compared to the unfertilized control and the farmyard manure. In the case of wet and dry digestates, the dry matter yield was 23% and 19% below the mineral fertilized level (Fig. 3).

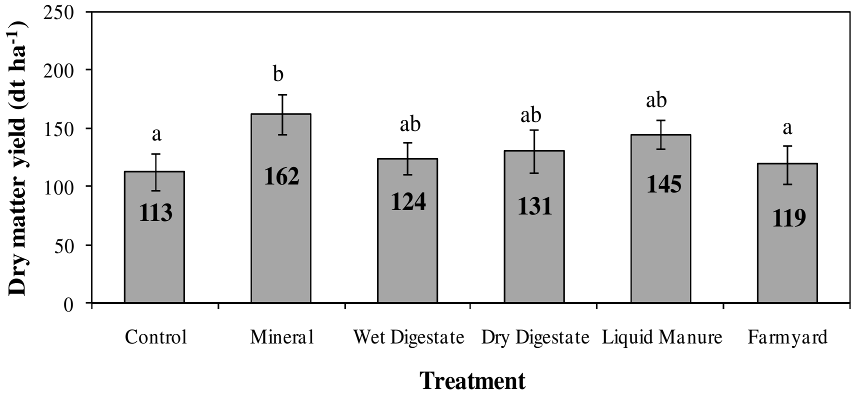

FIGURE 3 **Dry matter yield (dt ha^{-1}) of *Sorghum bicolor* var. *sudanense* using 120 kg N ha^{-1} per treatment.** Mean value, Standard Error and Tukey Test with α: 0,05%. Means from the same homogeneous group are followed by the same letter.

TABLE 3 **Abundance (individuals m^{-2}) and biomass (g m^{-2}) of earthworms 1 month after application of 120 kg N ha^{-1} in various organic fertilizer treatments and an untreated control.** Mean Values and Tukey Test α: 0,05%. Means from the same homogeneous group are followed by the same letter.

	Control	Wet Digestate	Dry Digestate	Liquid Manure	Farmyard Manure
Abundance (Individuals m^{-2})					
Total Number	61 ^{a}	93 ^{a}	101 ^{a}	124 ^{a}	139 ^{a}
Total Endogeic	58 ^{a}	89 ^{a}	100 ^{a}	120 ^{a}	136 ^{a}
Total Anecic	1 ^{a}	4 ^{a}	1 ^{a}	2 ^{a}	2 ^{a}
Total Juvenils	54 ^{a}	86 ^{a}	96 ^{a}	106 ^{a}	127 ^{a}
Total Adults	5 ^{ab}	6 ^{ab}	4 ^{a}	14 ^{b}	10 ^{ab}
Biomass (g m^{-2})					
Total Biomass	8,57 ^{a}	11,40 ^{a}	13,38 ^{a}	23,06 ^{a}	16,16 ^{a}
Total Endogeic	8,03 ^{a}	10,74 ^{ab}	13,32 ^{ab}	22,22 ^{b}	18,85 ^{ab}
Total Anecic	0,37 ^{a}	0,66 ^{a}	0,05 ^{a}	0,65 ^{a}	0,12 ^{a}
Total Juvenils	4,26 ^{a}	7,44 ^{a}	8,90 ^{a}	9,67 ^{a}	9,95 ^{a}
Total Adults	4,14 ^{a}	3,67 ^{a}	4,15 ^{a}	12,91 ^{a}	8,86 ^{a}

One month after fertilization with the same amount of nitrogen for each treatment (120 kg N ha^{-1}) and an untreated control as comparison, the highest abundance of earthworms was found in the farmyard manure plots and the highest biomass was observed in the liquid manure. The abundance and biomass in all other treatments were lower (Table 3). Endogeic spieces (*Aporrectodea caliginosa, Aporrectodea icterica,* and *Aporrectodea rosea*) were clearly dominant and anecic species (*Aporrectodea longa* and *Lumbricus terrestris)* amounted to only 1 to 4 individuals m^{-2}.

4 DISCUSION AND CONCLUSIONS

In a loamy sand soil the highest grain and dry matter yield was achieved by the application of 120 kg ha^{-1} N mineral fertilizer. This probably was due to the availability of nitrogen in a chemical form that could directly be assimilated by the crop. Comparable results were observed applying also 120 kg ha^{-1} N, but in a combination of 80 kg ha^{-1} N wet digestate in autumn and 40 kg ha^{-1} N mineral fertilizer in spring. It is known that sandy soils are characterized by low water holding capacity and excessive drainage of rain and irrigation water, leading to poor water use efficiency by crops. Probably the application of wet digestate in autumn lead to lower losses of nitrogen through leaching processes, as soon as the nitrogen is released gradually from the wet digestate after the mineralization process, allowing the plant to assimilate the nitrogen continuosly. The application of 80 kg ha^{-1} N of mineral fertilizer in a sigle dose in spring, lead to better results than an application of wet digestate at the same rate.

In a clayey soil, the best results were achieved by the application of 150 kg ha^{-1} N mineral fertilizer splitted in autumn and spring. Using the same amount of nitrogen, comparable results were observed for the application of dry digestate splitted in autumn and spring. Mineral anions like nitrates, are repelled by negative charges on soil colloids. These anions, remain mobile in the soil solution and are succeptible to leaching. But due to the high water holding capacity of clayey soils, the retention of nitrate ions is higher, enabling the bacterial nitrification to take place over a longer time. By the application of less nitrogen (100 kg ha^{-1} N), the dry matter yield was quite comparable by the use of digestate as well as by the use of mineral fertilizer.

One month after the application of the different fertilizers, the highest abundance of earthworms was found in the treatment fertilized with farmyard manure. It is known that organic manures are one of the most important factors in increasing the abundance of earthworms in agricultural soils due to the increased food supply (Edwards and Lofty 1982). In addition, the C/N ratio of the farmyard manure was higher. Aira et al. 2006 has observed that fertilizers with high C/N ratios have a strong positive influence on earthworm populations. Ernst et al. 2007 found that the organic matter of digestates is more difficulte to be decomposed by earthworms, compared to conventional organic fertilizers. After the use of digestates the abundance of earthworms were lower by 20 to 25 individuals m^{-2} than for liquid manure and farmyard manure. In the case of the liquid manure the abundance of adults was significantly higher than in the treatment with dry digestate which led to a higher total biomass (Table 2). This could be due to the fact that the availability of readily usable organic substances as a result of the fermentation process is lower in the digestates. Another aspect could be the higher NH^{4+}- N concentrations and higher pH of the digestates (Ernst et al., 2007).

However, further studies need to be done in order to understand and confirm the effect of the digestates on the yield and on the soil biological status.

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