Fertilizer value of field applied digestates

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Abstract
Anaerobic digestion (AD) leads to several changes in the composition of the resulting digestates compared to the original feedstock, which are relevant for the plant availability of macro- and micronutrients after field application. Increased NH_4^+-N content in digested compared to undigested slurries does not guarantee improved uptake efficiency of slurry N and increased savings in fertilizer N. AD of crop residues and cover crops leads to an increase in the total amounts of mobile organic manures within the farming system. This results in a higher N use efficiency and an increased scope for target oriented N application in time and space, when needed by the crop, as an alternative to the site bound soil incorporation as green manures. AD of dairy manure appears to reduce the fraction of immediate plant available phosphorus and micronutrients. However, this does not affect short term crop availability under field conditions. Current knowledge about sulfur losses during AD and fertilizer value of digestates is very scarce.

Introduction
Anaerobic digestion (AD) for biogas production leads to many changes in the composition of the resulting digestates compared to the original feedstock (ammonium content, pH, carbon to nitrogen ratio, etc.), which are relevant for the plant availability of macro- and micronutrients after field application. Many farmers and advisers expected higher nutrient use efficiency by using digestates instead of the undigested feedstocks. This presentation addresses the effects of AD on digestate composition and their fertilizing effects, and it will give an overview of the state of the art.

Material and Methods
A compilation of the available data on the effects of AD on manure characteristics and fertilizer effects under field conditions was carried out, including publications in peer-reviewed journals as well as in “grey literature” [1].

Results and Discussion
Digestates show higher ammonium (NH_4^+):total nitrogen (N) ratios, decreased organic matter contents, decreased total and organic carbon contents, reduced biological oxygen demands (factor 5 - 13), elevated pH values, smaller carbon to nitrogen ratios, and reduced viscosities than undigested animal manures. Nutrient composition of digestates varies depending on the used feedstocks (Table 1). Digestates from feedstocks with a high degradability (e.g. cereal grains, poultry and pig manures with a diet high in concentrates, food wastes) are characterized by high nutrient contents, and a high NH_4^+-N:total N ratios as well as narrow C:N ratios. Cattle manures or fibrous feedstocks (e.g. many household wastes, many dedicated energy crops like silage maize, grassland, clover-grass ley) lead to a low NH_4^+-N:total N ratio. Furthermore, there are strong differences between liquid and solid digestates. The very low N contents of solid digestates (Table 1) indicate very high unproductive N losses during storage or composting of the solid fraction.

For the year of application of organic manures, it is generally assumed that the fraction of plant available N is closely associated to the manures’ NH_4^+-N contents. Comparisons of digestate applications with mineral N fertilizers based on equivalent amounts of total N have been shown lower fertilizer N-values than the mineral N fertilizers. However, if the application was only based on equivalent amounts of the NH_4^+-N fraction in the digestate, comparable apparent NH_4^+-N recoveries of digestates and mineral fertilizers were reported. Simultaneously, with digestate field application soil N_{org}-accumulation takes place, enhancing soil N_{org}-mineralization even after a single digestate application. The net N_{org}-mineralization in the year of application ranged between 10 and 15 %.

Table 1: Examples for nutrient content (% DM) and NH_4^+-N/total N as well as C:N ratio of liquid and solid digestates derived from different feedstocks

Feedstocks	n	DM	N	NH_4^+	P	K	S	OM	C:N
Liquid digestates									
dairy slurry	19	9.20	3.89	2.06	0.66	4.71	-	63.8	8.4
dedicated energy crops [1)]	85	6.77	8.11	3.93	1.45	6.45	-	70.3	5.5
household wastes [1)]	64	12.0	4.47	1.55	0.68	3.24	-	58.1	8.6
food wastes	97	3.34	16.3	12.2	2.21	4.49	0.86	56.5	2.1
Solid digestates									
dedicated energy crops [1)]	33	37.9	2.69	0.16	1.17	2.55		83.7	21.0
household wastes [1)]	11	45.8	1.84	0.13	0.60	1.20		61.0	19.7

[1)] Nutrient content data provided by the German certification association for composts and digestates (Bundesgütegemeinschaft Kompost). Abbreviations: n – data size; DM – dry matter, N – nitrogen, P – phosphorus, K – potassium, S – sulphur, OM – organic matter, C:N – C:N ratio

Comparisons between digested and undigested slurry in pot experiments indicate a higher apparent N recovery for digested slurry. Field experiments with the application of equivalent amounts of total N indicate that the uptake of N from liquid digested animal slurry equalled that of undigested slurry after surface application, despite the higher NH_4^+-N content of the digestate. A significant effect of AD on crop yields and N uptake could only be found in experiments where the manures are incorporated into the soil shortly after field application, indicating that substantial parts of N might have been volatilized as NH_3 when not incorporated after field application.

It is often stated that degradation processes during AD will improve also phosphorus (P) plant availability. However, most available results from field experiments indicated no effects of AD on manure P availability. AD has potentially the opposite influence on crop P availability, as often stated. Manure pH strongly influences the solubility of P and micronutrients. Raising the pH moves the chemical equilibrium towards the formation of phosphate ($HPO_4^{2-} \rightarrow PO_4^{3-}$) and subsequent precipitation as calcium (Ca)- or magnesium (Mg)-phosphate (e.g. $Ca_3(PO_4)_2$). Simultaneously, the binding form of other elements such as iron (Fe) may also be influenced by AD, affecting P turnover and precipitation processes during AD. The fraction of dissolved P, mineralized during AD, associates with suspended solids. The water-extractable P-fraction and ratios of extractable nutrient:total-nutrient for Ca and Mg decreased substantially during AD. Mineralization of N, P and Mg combined with a substantial increase of the manure pH can enhance the formation and crystallization of struvite. This process can be used to remove N and P from manures to reduce the P and N loadings. Many ionic species (e.g. Ca^{2+}, K^+, CO_2^{-3}) can influence struvite formation by reacting with its component ions. Therefore, digestates contain only trace amounts of Ca^{2+}, Mg^{2+} and inorganic P in solution.

Sulfur (S) is a major essential nutrient, and S deficiency becomes problematic in a growing number of regions. Redox level is an important factor when determining S reactions in a system. Therefore, degradation of OM forms sulfate, which, in the absence of O_2, reacts with protons to hydrogen sulfide (H_2S) and other molecules increasing the digester pH and leading to a strong decrease of sulfate concentration and increase of sulfide and C-bonded S concentrations, metal-sulfide precipitation and sulfur volatilization. The formation of H_2S, methanethiol (CH_3-SH), dimethyl-sulfide ($(CH_3)_2S$), and dimethyl disulfide (CH_3SSCH_3) slurry is redox dependent, while carbonyl sulfide (COS) and carbon disulfide (CS_2) are relatively constant and in low amounts at all redox levels. Most of the S emanating from the slurry is produced under anaerobic conditions between 0 and -200 mV. H_2S contents are proportional to feedstock S contents. Protein-rich feedstocks may increase H_2S content in digestates, as S is introduced mainly as a constituent of amino acids. No data were found addressing the digestate plant S availability. Sulfate is the plant available sulfur form. Sulfide is expected to be readily oxidized to sulfate under oxic conditions. Although no data were found about S volatilization after field application of digestates, a high volatilization risk during manure storage and after manure spreading can be expected due to the high proportion of potentially volatile S compounds in digestates.

Conclusion and Perspectives

Digestates have potential benefits regarding N availability and crop yields in comparison to untreated animal manures, as shown by pot experiments. However, under field conditions the available data on agronomic assessments of digestates from animal slurries differ in their results with small or inconsistent benefits compared to undigested slurries. Increased slurry NH_4^+-N share in digested slurries does not guarantee improved utilization efficiencies of slurry-N. Significant positive effects can only be expected if the digestates are applied directly with incorporation into the soil immediately after field spreading. Handled like this, digestates provide plant available N corresponding to their NH_4^+-N-content plus a small part of the N_{org} fractions (10 – 20 %). The contradiction of the results from pot and field experiments emphasizes the need of field experiments to get a reliable assessment of the most important factors driving the agronomic effects of digestate application.

There are no systematic studies available on the influence of single feedstocks on nutrient contents and nutrient speciation in digestates, also including the C_{org} and organic N (N_{org}) components. For a better understanding of the driving factors governing N-turnover in the soil, an accurate characterization of digestates' nutrient and OM composition, combined with experiments to assess the N-mineralization and N-immobilization processes after field spreading, would be essential for a better understanding of the driving factors governing N-turnover in the soil. Research addressing the influence of the single feedstocks and the design of the fermentation process on composition of digestates is also needed. Furthermore, a better knowledge on the influence of single feedstocks on digestate composition is an important key for optimization of the feedstock management throughout the year, in order to obtain a higher share of the circulating N for spring amendments.

References

[1] 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.