Anaerobic digestion of plant biomass and animal manure: effect on C retention in soil and plant available N

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Abstract
We compared the release of C and N from untreated and anaerobically digested plant biomasses and animal manures. Based on losses of C during the plant biomass (feed) passage in cattle, during anaerobic digestion (AD), and during incubation with soil, the retention of C in soil was estimated. When related to the amount of C originally present in the feed, the digestion by cattle and/or AD did not significantly affect the longer-term retention of C in soil whereas the contribution to the labile soil C pool differed. Digestion by cattle and AD increased the release of inorganic N but with no simple relationship between N release and C retention. The increase in N availability due to AD was equivalent to 10-35% of total N in slurry, but after AD of plant biomass and faeces the N availability increased significantly more.

Introduction
Anaerobic digestion (AD) of plant biomass, animal manures and organic wastes for methane production is promoted to reduce fossil energy use. The availability of N to crops is increased during AD and as all other plant nutrients are retained, the digested residue represents a valuable fertilizer. However, it is not clear how AD affects the C turnover in soil. We present results of studies comparing the retention of C in soil after application of cattle feed, cattle faeces, digested feed and digested faeces, all derived from the same batch of feed mixture (*Exp. 1*). Using slurries retrieved from pig and cattle farms, we compared net N mineralization of digested and corresponding untreated slurries (*Exp. 2)*. Using confined plots in the field (*Exp. 3*), we determined the mineral fertilizer replacement value of animal slurries and different plant biomasses before and after AD.

Material and Methods
A dairy cattle feed mixture (mainly maize silage) and the corresponding faeces, animal slurries from cattle and pig farms, and different plant biomasses were subject to AD in a continuously fed pilot-scale digester run under thermophilic conditions (47- 53°C)[1, 2]. Three experiments were carried out involving untreated and AD-treated materials.
Experiment 1: The release of CO_2 from a sand soil and a sandy loam soil amended with untreated and AD treated cattle feed and faeces was determined over a 245 days period using a RESPICOND VI held at 20°C. The net release of CO_2 was determined after subtracting CO_2 released from a control soil. The C mineralization data were fitted to a three-pool decomposition model and the proportion of labile and stable C retained in soil calculated. The loss of C during animal digestion and AD was estimated to provide an overall C balance [2].
Experiment 2: The net release of mineral N from the materials used in *Exp. 1* and from untreated and AD treated pig and cattle slurries was determined over a 119 days period after application to a loamy sand soil similar to the soil in *Exp.1*. The incubation was run at 20°C and mineral N in the soil was extracted with 1*M* KCl after 4, 7, 14, 28, 84 and 119 days of incubation [3]. The net release of mineral N was determined after subtracting mineral N measured in a control soil.
Experiment 3: The mineral fertilizer replacement value (MFRV) of N in untreated and AD treated manures (similar to slurries in *Exp. 2*) and in AD treated plant biomasses were determined under field conditions using confined plots on a loamy sandy soil. Grain yield and N uptake were compared to treatments given mineral N fertilizer [3, 4]. The manures and plant biomass were applied in spring. For winter wheat the materials were surface-banded (simulating a trailing hose

application; 150 kg total N ha^{-1}). For spring barley the materials were applied before planting in a band at 10 cm depth (simulating a direct injection; 80 kg total N ha^{-1}).

Results

The loss of C during AD was 80% for feed and 46% for cattle faeces, based on the ratio of total C to ash content before and after AD. The loss of C in the cow was about 70% [2]. When accounting for these C losses and the net CO_2 release during 100 days of incubation, the cumulated C loss was almost similar for digested feed, faeces and digested faeces (Table 1). The net release of mineral N after the same period was however quite variable. After AD of the cattle feed, the net mineral N release in soil increased from 28% to 82% of the total N, while AD of cattle faeces (from cattle fed the same diet) increased the net mineral N release from 25% to 62% of total N (Table 1). Feed total N and faeces N are not directly comparable as only about 45% of the N excreted from cows fed this type of diet ends up in the faeces [5]. During AD only insignificant N losses are expected and thus the same amount of N should be present before and after AD. Despite similar losses of C from untreated and AD-treated faeces, the mineral N release differed significantly suggesting that the different paths for metabolism of the C originally present in the feed had significant effects on N retention/mineralization in soil.

After 100 days of incubation, less C was lost from untreated than from AD treated feed. This may at least partly explain the smaller N release from the untreated feed as the intense microbial activity associated with assimilation of this labile substrate may result in a high N retention relative to the C retention.

Table 1. Net C loss and mineral N release depending on handling strategy for organic materials. The calculations were based on a feed mixture (plant biomass) applied directly to soil, faeces after cattle feeding, both materials with and without AD before application to soil [2]. Net CO_2-C and mineral N release was measured after application to a loamy sand soil (*Exp. 1* and *Exp. 2*).

Organic material	C loss in cow and by AD	CO_2-C release from soil after100 days	Cumulated C loss	Net mineral N release in soil after 100 days[b]
	% of initial C in feed	% of C applied to soil	% of initial C in feed	% of total N input
Feed	0	73	73	28
Digested feed	80	36	87	82
Faeces	70[a]	47	84	25
Digested faeces	84	22	87	62

[a]Based on 70% digestibility of feed C [2].
[b]Mean of mineral N release after 84 and 119 days of incubation.

When modelled from the CO_2 evolution over a 245 days incubation period the proportion of C originally present in the feed and retained in the soil for decades accounted for 12-14% for feed, AD-treated feed, faeces and AD-treated faeces (Figure 1). This suggests that the treatment of the plant biomass (feed) before being added to soil has insignificant effects on its contribution to the long term C sequestration in soil. However, the contribution of C to the labile soil C pool, and thus the input of organic material supporting microbial activity and the associated soil N mineralisation-immobilization turnover, differs significantly among the different materials. When the feed was added directly to the soil, 86 % of the feed-C entered the labile soil C pool. When the feed was first digested by a ruminant and the resulting faeces then subject to AD, the contribution to the labile soil C pool corresponded to just 4 % of the C originally present in the feed.

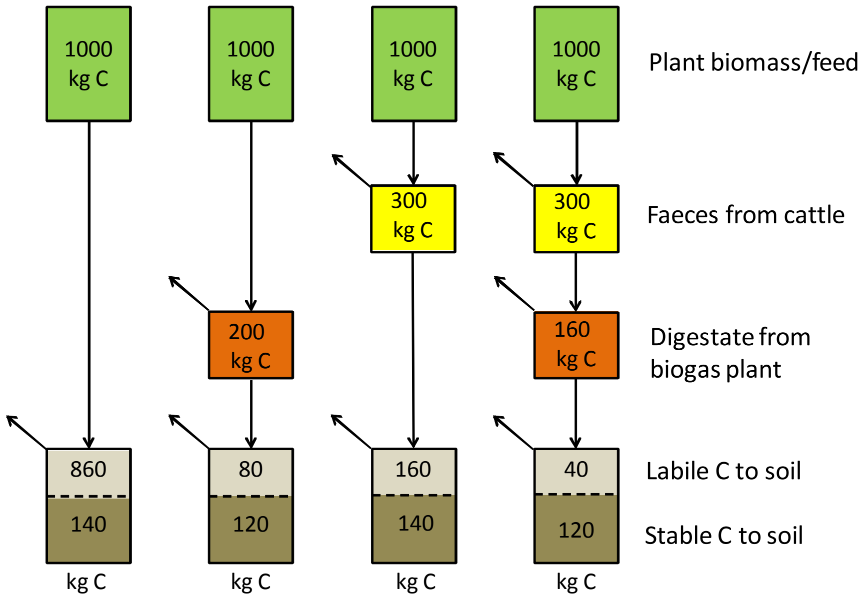

Figure 1. ***Exp. 1*****: Estimated long term retention of C in soil depending on handling strategy for organic materials derived from the same plant material/feed. Same scenarios as in Table 1 but here estimated from average CO_2 release from two soil types. Based on data from** [2]**.**

After AD of manures the concentration of ammonium-N increased and more mineral N was released during soil incubation (Figure 2). For pig and cattle slurry the increase in mineral N release was equivalent to 10-35% of total slurry N while the increase in mineral N release after AD of feed and faeces was significantly higher.

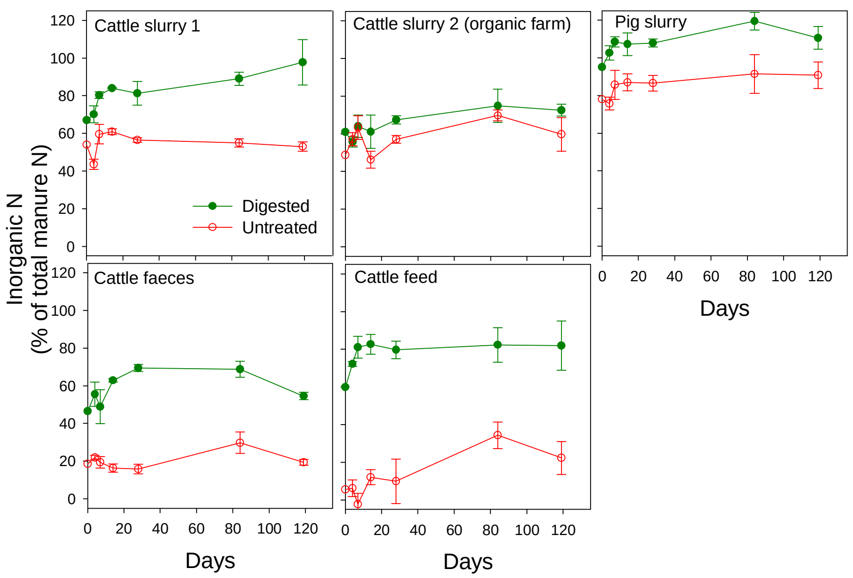

Figure 2. ***Exp. 2*****: Net release of inorganic N in soil after adding untreated and AD treated materials to a loamy sand soil (at 20°C). Bars indicate standard errors (n=3).** [3]

Table 2 shows that AD increased the N fertilizer value of cattle slurries applied to barley from 58-75% to 69-82% of total N. The N fertilizer value of digested and injected plant materials was 73-77% and similar to that of digested cattle slurry. This was in accordance with the measured high net mineral N release from digested feed in the incubation experiment (*Exp. 2*). The incubation in *Exp. 2* was performed in the laboratory at 20°C which was higher than mean temperature in the field. Therefore slightly more N could be expected to be released under the laboratory conditions. Surface-banding of manures rich in fibres (cattle and plant-based slurries) significantly reduced the N fertilizer value compared to injection, indicating a significant ammonia loss from the surface-

applied manures. This was probably due to poorer infiltration of the more fibre-rich slurries in combination with a high pH after digestion. This is emphasising that injection or fast incorporation is particularly important for AD-treated cattle slurry and plant biomass.
We observed no difference in N fertilizer value of digested and untreated pig slurry after injection. The lack of effect of AD could be due to an unexpected high fertilizer value of untreated pig slurry as also observed in other studies [4].

Table 2. *Exp. 3*: Chemical composition of untreated and corresponding AD treated manures and mineral fertilizer replacement values (MFRV) measured after injection in spring barley and surface-banding in winter wheat (n=4). [3]

Manure	Total N kg N/t	NH_4-N/total N %	DM %	pH	MFRV Spring barley % of total N	MFRV Winter wheat % of total N
Cattle slurry 1	3.00	54	6.43	6.72	75	37
Cattle slurry 1 digestate	3.05	67	4.82	7.52	82	38
Cattle slurry 2 (organic farm)	2.92	49	6.95	8.17	58	30
Cattle slurry 2 digestate	2.94	61	4.65	8.09	69	49
Pig slurry	2.81	78	3.45	7.71	91	75
Pig slurry digestate	2.57	95	1.46	8.4	89	87
Clover-grass digestate	4.53	61	5.18	7.81	73	57
Lupine digestate	2.78	68	3.5	7.71	73	48
Triticale-vetch digestate	2.69	59	5.25	7.48	77	43
LSD ($P<0.05$)	-	-	-	-	14	19

Conclusion and perspectives

The digestion of feed in cows and/or anaerobic digesters did not significantly affect the long-term retention of C in soil when the retained C was related to the quantity of C originally present in the plant biomass. This indicates that different management of manures, e.g. for biogas production, has negligible influence on C sequestration in soil. However, the contribution to labile soil C was strongly affected by AD. The availability to plants of manure/plant N increased significantly by animal digestion and AD, indicating no direct relationship between manure N release and C retention in soil. Especially for manures rich in organic N there was a large increase in N availability after AD and the fertilizer value of injected plant-based digestates was equivalent to 73-77% of total N.

References

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