Two biochars (made from insect frass and woody fraction of green waste at 450° pyrolysis temperature) were added (at 5%$_{w/w}$) during semi-continuous anaerobic digestion of organic kitchen waste (VGF) and chicken manure (2-3%$_{w/w}$) or to the digestate after the process.

Biochar use during biomass processing

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1) Anaerobic digestion

Two biochars (made from insect frass and woody fraction of greenwaste at 450° pyrolysis temperature) were added (at 5 % w/w) during semi-continuous anaerobic digestion (AD) of organic kitchen waste and chicken manure (2-3 % w/w) or to the digestate after the process (*Fig. 1-2*). There was no effect of biochar on biogas yield and composition, however, biochar addition resulted in less NH_3 in the biogas and less NH_4^+-N in the digestate, indicating binding of NH_4^+-N onto the biochars. Addition of biochar during the AD process resulted in a higher OM content and C/N ratio of the digestate, but not when the biochar was added to the digestate afterwards (*Table 1*). Adding both biochars afterwards decreased the NH_4^+-N content and the NH_4^+-N / total N ratio. Adding frass biochar during AD or afterwards, resulted in a higher P and K content (*Table 1*). Soil application of the biochar-enriched digestates at 170 kg N ha^{-1} did not lead to extra N losses as there were no differences in greenhouse gases and NH_3 emissions between the treatments. However, soil application of the biochar-enriched digestates at a double N dose (340 kg N ha^{-1}) resulted in lower N_2O (only for frass biochar) and CO_2 emissions compared to the control (27 days), when biochar was applied during or after AD (*Fig. 3*). There was no effect on NH_3 emissions, indicating that the lower NH_3 emissions during AD with biochar did not lead to higher NH_3 emissions after soil application of the biochar-enriched digestates.

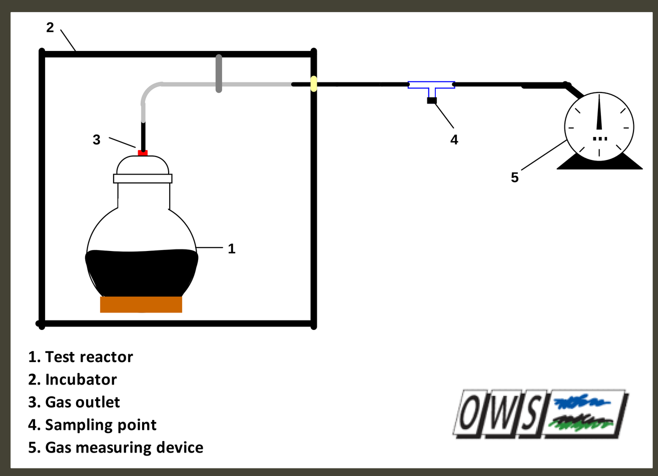

Fig. 1: Anaerobic digestion experiment at OWS

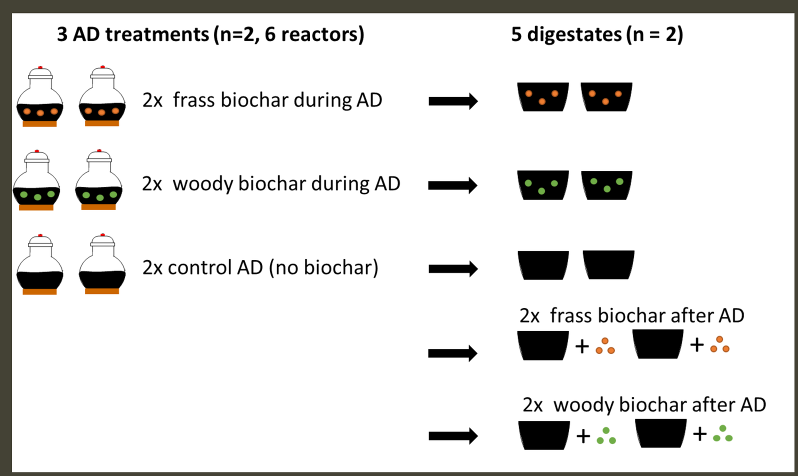

Fig. 2: Overview of the treatments

Parameter	Control	Woody biochar during AD	Frass biochar during AD	Woody biochar after AD	Frass biochar after AD
OC (% DM^{-1})	25.3 ± 1.1	30.3 ± 0.4	33.6 ± 0.2	27.4 ± 1.5	31.3 ± 1
TC (% DM^{-1})	27.2 ± 1	32 ± 0.4	34.7 ± 0.1	29.9 ± 0.6	32.8 ± 1.2
IC (% DM^{-1})	1.9 ± 0.2	1.7 ± 0	1.2 ± 0	2.5 ± 0.8	1.5 ± 0.3
Total N (% DM^{-1})	3.5 ± 0.3	3.2 ± 0	3.6 ± 0.4	3.2 ± 0.3	4.4 ± 0.4
C/N (-)	7 ± 0.3	9.4 ± 0.1	9.1 ± 0.9	8.4 ± 0.4	7.1 ± 0.9
OM (% DM^{-1})	53.2 ± 1.3	56.2 ± 0.1	58.2 ± 2.8	49.3 ± 3.6	52.3 ± 2.1
DM (% $fresh^{-1}$)	25.7 ± 2.7	29.2 ± 0.5	29.9 ± 2.5	31.1 ± 0.8	32.6 ± 0.2
Total P (g kg^{-1} DM)	7.4 ± 0.7	6 ± 0.4	9.9 ± 1.3	8.5 ± 5	10.7 ± 1.1
Total K (g kg^{-1} DM)	17.5 ± 1.3	18.1 ± 0.5	23.7 ± 0	16.8 ± 0.4	23 ± 0.4
Total Mg (g kg^{-1} DM)	10 ± 0.6	8.4 ± 0.3	8.6 ± 0.6	8.3 ± 0.9	9.3 ± 0.3
Total Ca (g kg^{-1} DM)	69.1 ± 5.2	55.2 ± 1.2	55.3 ± 4.4	82.7 ± 15.5	64.8 ± 18.3
Total Na (g kg^{-1} DM)	9.2 ± 0.7	7.4 ± 0.2	8.9 ± 0.1	6.9 ± 0.1	7.8 ± 0.1
Total Fe (g kg^{-1} DM)	6.1 ± 0.7	5.4 ± 0.1	4 ± 0.3	5.3 ± 0.1	5.7 ± 0.4
Total Al (g kg^{-1} DM)	6 ± 0.1	4.9 ± 0.1	4 ± 0.3	3.8 ± 0	5.1 ± 1.2
NO_3^--N (mg kg^{-1} DM)	< 0.65	< 0.65	< 0.65	0.77 ± 0.17	0.7 ± 0.06
NH_4^+-N (g kg^{-1} DM)	14 ± 1.41	11.45 ± 0.78	10.4 ± 0.71	10.05 ± 0.24	9.12 ± 0.21
NH_4^+-N / Total N (%)	39.8 ± 0.9	36 ± 2.5	28.6 ± 0.8	31.4 ± 2	21 ± 2.5
OUR (mmol kg^{-1} OM h^{-1})	14.9 ± 6.4	12.9 ± 3.7	16.3 ± 0.3	18.7 ± 2.3	12.1 ± 1

Table 1: Chemical characteristics of the digestates (n=2)

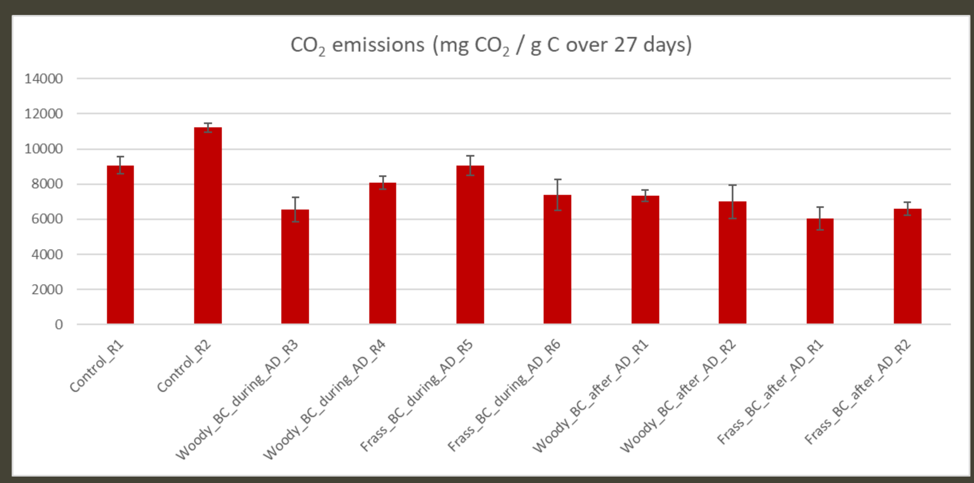

Fig. 3: CO_2 emissions per g C after soil application of the digestates (n=2)

2) Manure storage

In a first phase (20 days), biochar (woody fraction of greenwaste at 450° pyrolysis temperature) was added to cattle slurry at a rate of 10 % dry weight (10 g L^{-1}) in three replicates (*Fig. 4, left*). In a second phase (16 days), clinoptilolite (300 g), S° (6 g) and 240 g extra biochar (oak-based biochar) was mixed to the cattle slurry. Gaseous emissions were monitored by a semi-continuous multi-gas analyser (*Fig. 4, right*), and quality of solid and liquid fractions was assessed after separating the slurry by centrifuging (*Fig. 6*). Next, the enriched solid fractions were applied to soil at 170 kg N ha^{-1} to study the effects on gaseous emissions and C and N mineralization.

(1) Slurry storage: Adding clinoptilolite, a high dose of biochar (50 g L^{-1}), and a low dose of biochar (10 g L^{-1}) in combination with S° reduced the NH_3 emissions compared to the slurry without biochar (16 days, *Fig. 5*). There were no differences in N_2O and CO_2 emissions.

Fig. 4: Left: cattle slurry. Right: Measurement of gases during storage of cattle slurry

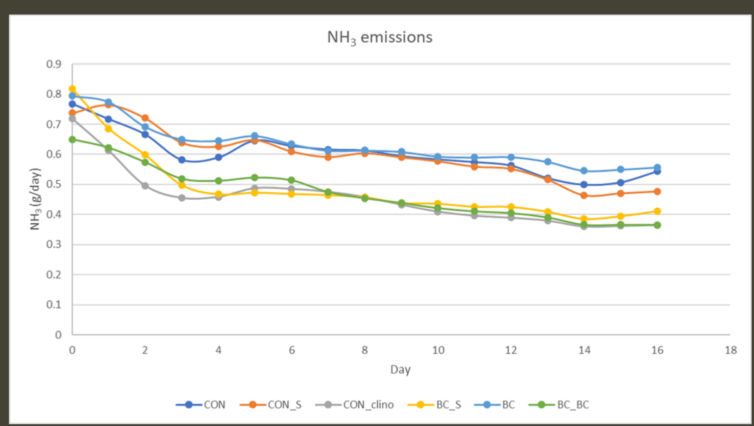

Fig. 5: NH_3 emissions during storage of cattle slurry

Fig. 6: Left: liquid fraction. Right: solid fraction after separation of the slurry

(2) Liquid and solid fractions: Adding clinoptilolite and extra biochar to the slurry increased the separation efficiency of the solid fraction from 36% to 40% and 49%, respectively. The pH-H_2O of the liquid fractions seemed not to be strongly affected by the amendments. Total N content of the liquid fractions was lowest for the clinoptilolite and biochar amendments. All amendments, except for S°, resulted in a decrease in NH_4^+-N content compared to the control liquid fraction.

Adding clinoptilolite to the slurry resulted in a drier solid fraction with a much lower C content. Further, the clinoptilolite-enriched solid fraction contained less nutrients (except for Fe and Al) compared to the control solid fraction. The biochar-enriched solid fraction contained a lower NO_3^--N and SO_4^{2-} content, more water-available P and a higher CEC than the control solid fraction. The double-biochar-enriched solid fraction had also a higher DM and OM content, a lower total N and NH_4^+-N content (resulting in a higher C/N). In contrast with the biochar-enriched solid fraction, the S°-enriched solid fraction contained almost 5 times more SO_4^{2-} and had a much higher CEC (the highest amongst the different solid fractions) than the control solid fraction.

(3) Soil addition of solid fractions: Soil addition of S°-enriched solid fraction resulted in significantly higher NH_3 emissions than adding clinoptilolite ($p = 0.01$). There was no effect from biochar on NH_3 emissions, indicating that the reduced NH_3 emissions during manure storage with biochar did not result in extra NH_3 emissions during soil application afterwards. Soil addition of double-biochar-enriched solid fraction resulted also in lower CO_2 emissions (ca. 50% reduction) compared to all other solid fractions.

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