NGI Technical note

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Gas emissions from biochar production at Mære Landbruksskole

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Sammendrag på norsk

Rapporten beskriver produksjonen av biokull fra kvister, halm og frø ved Mære Landbruksskole den 5.-6. juli 2023. Studien fokuserer på utslipp under pyrolyse, samt fuktighets-, karbon- og nitrogeninnholdet i råmaterialet og biokullet, målt ved hjelp av en avansert gassanalyseenhet. Ovnen som ble brukt til produksjonen var designet for å minimere utslipp, med en konisk form og en flammegardin for å forbrenne gasser som frigjøres under produksjonen.

Viktige funn inkluderer:

- Biokullutbyttet var lavere (12-16%) sammenlignet med tidligere eksperimenter (21-25%) på grunn av for høy oksygentilgang.
- CO2-utslipp per kg biokull var høyere, noe som indikerer en blanding av forbrenning og pyrolyse.
- CO- og metanutslipp økte med fuktighetsinnholdet i råmaterialet.
- Røykutslipp varierte med fuktighetsinnholdet, og minket for kvister, men økte for halm.
- Metanutslipp var lavere enn de 30 g/kg som brukes i biokullkarbonsertifisering, men fortsatt betydelige.
- NO- og NO2-utslipp var høyere på grunn av forhøyede temperaturer.
- Utslipp av SO2, HCl, NH3 og N2O ble rapportert for første gang, hvor N2O er spesielt relevant på grunn av dets høye globale oppvarmingspotensial.

Selv om biokullproduksjon kan binde karbon, er håndtering av utslipp avgjørende for å maksimere miljøfordelene.

Abstract

The report details the production of biochar from twigs, straws, and seeds at Mære Landbruksskole on July 5-6, 2023. The study focuses on the emissions during pyrolysis, and on moisture, carbon, and nitrogen content of the feedstock and biochar, measured using a high-tech gas analysis unit. The kiln used for production was designed to minimize emissions, featuring a conical shape and a flame curtain to combust gases released during production.

Key findings include:

- Biochar yield was lower (12-16%) compared to previous experiments (21-25%) due to excessive oxygen access.
- CO2 emissions per kg of biochar were higher, indicating a mix of combustion and pyrolysis.
- Emissions of CO and methane increased with feedstock moisture content.
- Smoke emissions varied with moisture content, decreasing for twigs but increasing for straws.
- Methane emissions were lower than the 30 g/kg used in biochar carbon certification, but still significant.
- NO and NO2 emissions were higher due to elevated temperatures.
- Emissions of SO2, HCl, NH3, and N2O were reported for the first time, with N2O being particularly relevant due to its high global warming potential.

While biochar production can sequester carbon, managing emissions is crucial for maximizing environmental benefits.

1 Materials and method

Biochar was produced at Mære Landbruksskole from twigs, straws and seeds the 5th and 6th of July 2023.

1.1 Moisture, carbon and nitrogen content

Moisture in twigs was measured with a Protimeter Timbermaster BLD5609 (1 % accuracy). Moisture in straws and seeds were measured by drying subsamples in the oven at 105 °C over night. Three moisture categories for twigs were used when making biochar, as well as two categories for straws and one category for seeds. Carbon and nitrogen content were measured in straws, seeds and biochar by element analysis at NMBU. Biochar 1-3 are explained in Table 1-1.

Table 1-1 Moisture, carbon and nitrogen content in feedstock and biochar. For biochar 1,2,3 see Table 1-1.

Feedstock	Category	Subsamples	Moisture (%)	Carbon (%)	Nitrogen (%)
Twigs	Dry	32	10,3 ± 1,27	-	-
	Half-dry	24	19,0 ± 3,27	-	-
	Wet	40	36,9 ± 16,8	-	-
Straws	Dry	3	11,0 ± 0,19	47,1 ± 0,21	0,96 ± 0,04
	Wet	3	17,2 ± 0,10	46,9 ± 0,44	0,87 ± 0,01
Seeds	Dry	3	11,2 ± 0,07	44,9 ± 0,06	1,90 ± 0,08
Biochar 1	-	3	27,3 ± 4,22	56,1 ± 13,3	0,95 ± 0,19
Biochar 2	-	3	33,2 ± 1,75	60,8 ± 13,2	1,15 ± 0,31
Biochar 3	-	3	28,1 ± 1,32	86,9 ± 0,32	1,15 ± 0,02

1.2 Kiln operation

The kiln used for biochar production was constructed by personnel at Mære Landbruksskole under instruction of NGI. The kiln had a conical shape to minimize oxygen access to the raw material during biochar production. This is because a covering flame curtain prevents oxygen from entering the pit by consuming oxygen itself. This flame also helps to combust the gases released during biochar production. The bottom of the kiln was cylindrical shaped to easily ignite the materials. The kiln was approximately 1.5 meters deep and 3.2 meters in diameter. To prevent contact with moist soil, the kiln was internally lined with cement. Holes were drilled in the bottom of the kiln to allow water to drain into the underlying materials (sand and gravel).

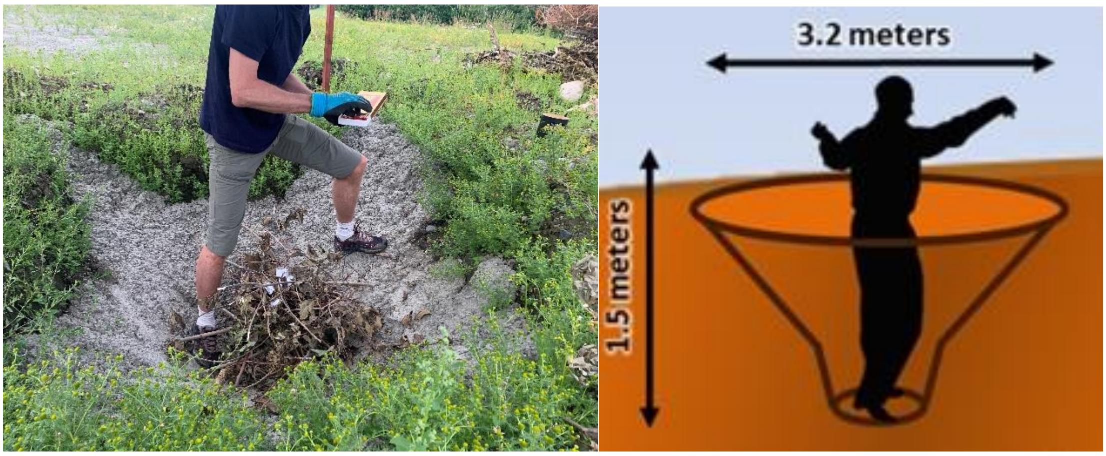

Figure 1 Left: kiln at Mære Landbruksskole. Right: cartoon showing ideal dimensions of kiln.

Over the kiln, a roof with a chimney was placed to collect gases from the biochar production. The roof was constructed by Mære Landbruksskole under the instruction of NGI. Inside the chimney, hoses were installed to guide the gases to measuring instruments.

Figure 2 Kiln at Mære Landbruksskole with roof to collect gases.

Gases were analysed with Gasmet Portable FT-IR measuring system. The gases analysed were H_2O, CO_2, CO, NO, NO_2, N_2O, SO_2, NH_3, HCl, HF, CH_4, C_2H_6, C_2H_4, C_3H_8, C_6H_{14}, CHOH, MEA, piperazine, AMP, MDEA, acetaldehyde, TOC and O_2.

C_2H_6, C_2H_4, C_3H_8, C_6H_{14} were combined into NMVOC (non-methane volatile organic carbon). Particles in the form of PM_{10} were analysed with a Thermo Scientific pdr-1500 instrument by use of photometric detection of particles (detection limit 0.1 µg/m^3). TSP was calculated from PM_{10}, assuming that TSP = 1.4·PM_{10}.

The results from the biochar production are shown in Table 1-1 and Tabell 1-2. Data from earlier work for comparison are shown in Tabell 1-3. Main observations from the results are as follows:

- The biochar yield was low (12-16%) compared to that in earlier experiments (21-25%). The explanation is that the twigs were too long, allowing too much oxygen to come in. The process has been half-way between full combustion and pyrolysis. This is underscored by the high CO_2 emissions per kg biochar – more gas was formed per kg biochar (8-11 kg) compared to earlier work (3-5 kg).
- CO and methane emissions increased with feedstock moisture content.
- Smoke emissions reduced with increased feedstock moisture content for twigs, but the opposite was observed for straws.
- Methane emissions from dry feedstock were not zero as in earlier measurements in Peru (Tabell 1-3) but lower than the 30 g/kg used in biochar carbon certification (except for wet straws). Methane emissions of 10-20 g/kg for dry and half-dry feedstock represent greenhouse gas emissions of 300-600 g CO_2-eq per kg biochar, which is lower than the C sequestration potential of biochar (2400 g per kg biochar) but not insignificant.
- CO and smoke emissions were in the same order of magnitude as in earlier work.
- NO and NO_2 emissions were much higher than in previous work, probably because of the higher temperatures due to overly high oxygen access. At high temperatures nitrogen from the air is oxidized to NO and NO_2.
- For the first time emissions of SO_2, HCl, NH_3 and N_2O from this technology have been reported. Especially the emissions of N_2O are relevant as N_2O (laughing gas) is the 3rd most important greenhouse gas with a warming potential 300 times higher than that of CO_2. Multiplied by 300, the N_2O emissions factors are in the range of 100-300 g CO_2-eq per kg biochar, which is still lower than the emissions of methane (10-30 g/kg biochar, which is 300-900 g CO_2-eq/kg biochar), but not negligible.

Table 1-1 Masses in and out, as well as biochar yield. Carbon content for twigs were estimated to be 48 % (red alder). (Lamlom & Savidge, 2003)

Feedstock	Sample name	Moisture (%)	Feedstock (kg)	Biochar (kg)	Startup fuel (kg)	Gass by diff (kg)	Feedstock C (%)	Biochar C (%)	Startup fuel C (%)	Yield, %				Biochar C yield (%)
										Biochar	Condensate	Gas	Sum	
Medium dry twigs, dry straws	Biochar 1	73	140,0	21,8	0,00	118,2	47 %	56,1 %	0,00 %	15,6 %	0,0 %	84,4 %	100,0 %	18,47 %
Medium dry twigs, wet straws, seeds	Biochar 2	67	147,0	20,9	0,00	126,1	47 %	60,8 %	0,00 %	14,2 %	0,0 %	85,8 %	100,0 %	18,42 %
Dry twigs, medium dry twigs, wet twigs	Biochar 3	72	66,1	7,89	0,00	58,21	48 %	86,9 %	0,00 %	11,9 %	0,0 %	88,1 %	100,0 %	21,75 %

Tabell 1-3 Gas emissions in grams per kg biochar. CO = carbon monoxide; CH4 = methane; NMVOC = non-methane volatile organic carbon; TSP = total suspended particles (smoke/aerosols); SO2 = sulphur dioxide; NO/NO2 = nitric oxides; N2O = nitrous oxide; NH3 = ammonia; HCl = hydrochloric acid.

Summary of emission factors (g/kg biochar)

Sample code	#	Feedstock	Moisture (%)	CO_2		CO		CH_4		NMVOC		TSP	
				Mean	Stdev	Mean	Stdev	Mean	Stdev	Mean	Stdev	Mean	Stdev
Twigs	1	Dry	10,3	10534	3472	210	79	10,8	3,6	2,7	1,6	118	26
	2	Medium dry dag2	19,04	10584	3862	295	57	19,5	6,8	5,3	3,4	76	11
	3	Medium dry dag1.1	19,04	7973	2746	309	128	20,0	8,2	5,7	3,1	118	87
	4	Medium dry dag1.2	19,04	9263	1387	167	30	10,7	2,1	3,6	2,2	65	15
	5	Wet	36,9	10536	6104	401	59	28,5	6,9	9,3	5,7	46	23
Straws	6	Dry	11	8015	3377	285	67	17,9	5,2	5,9	3,2	118	48
	7	Wet	17,2	7701	3301	461	150	40,4	16,7	14,7	9,0	272	97
Twigs and seeds	8	Medium dry	15,12	9175	3811	225	71	19,3	9,6	5,6	3,2	59	16

Summary of emission factors (g/kg biochar)

Sample code	#	Feedstock	SO_2		NO		NO_2		N_2O		NH_3		HCl	
			Mean	Stdev	Mean	Stdev	Mean	Stdev	Mean	Stdev	Mean	Stdev	Mean	Stdev
Twigs	1	Dry	1,2	0,7	22,9	10,6	4,5	1,0	0,17	0,09	0,61	0,23	2,1	0,2
	2	Medium dry dag2	2,2	0,2	23,8	9,5	10,2	2,2	0,37	0,19	0,59	0,26	2,1	0,3
	3	Medium dry dag1.1	2,4	0,5	14,6	6,5	4,5	1,9	1,02	0,45	0,16	0,15	0,9	0,3
	4	Medium dry dag1.2	2,5	0,7	17,9	3,2	3,6	0,9	0,73	0,04	0,00	-	1,0	0,3
	5	Wet	2,8	0,4	27,2	18,1	14,8	2,6	0,42	0,40	0,44	0,37	2,8	0,4
Straws	6	Dry	3,5	0,8	21,1	8,6	6,1	1,8	0,87	0,15	0,13	0,11	1,1	0,3
	7	Wet	3,2	1,3	14,7	7,7	19,6	6,8	0,23	0,22	0,19	0,21	3,5	0,9
Twigs and seeds	8	Medium dry	3,3	0,8	19,8	9,7	8,0	2,8	1,46	0,98	0,01	0,03	1,4	0,5

Tabell 1-2 Data from earlier work as a comparison (Cornelissen, Sørmo, Rosa, & Ladd, 2023).

Run	Feedstock Moisture	Bio-mass in	Biochar out	Dura-tion	Biochar yield	Biochar C	Biochar H	n[a]	CO_2	CO	NMVOC	CH_4	TSP	NO_x
	%	kg dw	kg dw	min	%	%	%		g kg^{-1} biochar					
Kon Tiki soil pit dry	14.7 ± 3.4	85.3	21.2	51	24.8	81.2 ± 1.6	2.62 ± 0.30	25	3633	101 (60–181)	0.79 (0.00–2.82)	0.0 [h]	62 (29–97)	0.012 ± 0.035
Kon Tiki soil pit half-dry	29.0 ± 12.4	82.1 [b]	17.4[b]	31	21.2[b]	84.0 ± 1.1[b]	2.80 ± 0.24	18	4668	118 (84–203)		0.0 [h]	69 (33–87)	0.004 ± 0.008
Kon Tiki soil pit wet	41.0 ± 11.6	82.1[b]	17.4[b]	34	21.2[b]	84.0 ± 1.1[b]	2.80 ± 0.24	16	3049	206 (145–273)		605 (485–996)	21 (16–39)	0.000

2 Referanser

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