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Effect of biochar produced from different biomass sources and at different process temperatures on methane production and ammonia concentrations in vitro

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ABSTRACT

The effects of different biochars on in vitro rumen gas production and fermentation characteristics were investigated using a two (biochar inclusion level, 10 and 100 g biochar/kg substrate) x two (process temperature, 550 or 700 °C) × five (biomass source, *Miscanthus* straw, oil seed rape straw, rice husk, soft wood pellets or wheat straw) factorial design. The amount of biochar included in incubations had no effect on in vitro fermentation. Overall, inclusion of biochar reduced total gas production to 0.96 ($P < 0.001$) and methane (CH_4) production to 0.95 ($P < 0.001$) of that in control (no added biochar) incubations. There were no differences in gas or CH_4 production between the biomass sources used to produce biochar but total gas ($P = 0.058$) and CH_4 ($P = 0.010$) production were slightly greater when biochar was produced at 700 rather 550 °C. Addition of biochar to incubations did not change total amounts of volatile fatty acids (VFA) or acetic acid produced during in vitro fermentation; however, the amounts of propionate (0.94; $P < 0.001$) and butyrate (0.96; $P = 0.021$) were reduced when biochar was added to incubations. Process temperature had no effect on VFA produced; however, total VFA and the amounts of acetic and butyric acids produced were influenced by biochar biomass source. Ammonia concentrations at the end of incubations were overall 0.84 of control concentrations ($P < 0.001$)when biochar was added. Both process temperature and biochar biomass source influenced ammonia concentrations which were greater for biochar produced at 700 than 550 °C; concentrations were lowest for biochar produced from *Miscanthus* straw and greatest for rice husk with oil seed rape straw, soft wood pellets and wheat straw intermediate. Adding biochars with a range of compositions to in vitro assays produced only small reductions in CH_4 production. However, the absence of any negative effects of biochar coupled with the observed reduction in ammonia concentrations makes it possible that including biochar in livestock feed could be a practical means of applying biochar to pasture and soil.

1. Introduction

Methane (CH_4) emissions arising from the enteric fermentation of feed by ruminant livestock is an important contributor to global greenhouse gas emissions. For example, in 2014 in the United Kingdom (Department of Energy and Climate Change, 2016), enteric CH_4 emissions were estimated to account for 23.8 Mt carbon dioxide equivalents or 48% of total greenhouse gas emissions from the

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agriculture sector. There is therefore a need to develop strategies to mitigate CH_4 emissions and Hristov et al. (2013) distinguished those that directly address enteric fermentation; that focus on manure management and those that target animal husbandry (where animal husbandry includes genetics, health and fertility).

Manufacture and use of biochar has the potential to mitigate the impact of agriculture on greenhouse gas emissions in various ways. Biochar is the solid, carbon-rich product of biomass pyrolysis; the controlled heating of biomass at high temperature with deliberate exclusion of oxygen. Converting degradable biomass into recalcitrant biochar before adding it to soil demonstrably sequesters carbon into the land. It has also been found to suppress soil-based emissions of CH_4 and nitrous oxide (Sohi et al., 2010; Gurwick et al., 2013). The reason for the latter effects remain uncertain, but probably involve the general porosity of biochar and the large negative charge gradually developed across its large surface area (Kammann et al., 2017).

The inclusion of biochar in ruminant diets has been investigated for two reasons. First, biochar may reduce enteric CH_4 emissions (Leng et al., 2012; Hansen et al., 2012; Calvelo Pereira et al., 2014) and secondly, faecal excretion of dietary biochar may provide an effective means of transferring biochar into slurry or on to pasture (Calvelo Pereira et al., 2014; Joseph et al., 2015). Responses to the inclusion of biochar in rumen in vitro assays have been variable ranging from no effect (Calvelo Pereira et al., 2014) to a 13% reduction (Leng et al., 2012). As the properties of biochar are dependant on both the temperature of pyrolysis and the biomass source from which it was prepared, such variation is not surprising. The objective of the current work was therefore to determine whether biochar suppressed CH_4 production in vitro and by using a range of biochars with defined chemical and physical compositions to investigate the attributes of biochar responsible for suppressing CH_4 in vitro.

2. Material and methods

This experiment was conducted at Scotland's Rural College (SRUC) Beef and Sheep Research Centre in Edinburgh in 2013. The experimental protocol was approved by SRUC's Animal Welfare and Ethical Review Body, the Animal Experiments Committee and was conducted in accordance with the requirements of the UK Animals (Scientific Procedures) Act, 1986.

2.1. Biochar

The experiment used 10 standard biochars provided by the UK Biochar Research Centre, University of Edinburgh. These were manufactured in a scalable 20 min process optimised for research use, comprising a rotating kiln heated indirectly and electrically. The biochars differ by their source biomass (five granular biomass sources: rice husks and pelleted *Miscanthus* straw, oil seed rape straw, wheat straw or soft wood) and peak processing temperature (550 or 700 °C). A summary of biochar composition is given in Table 1. Full details of biochar production and composition can be found at (http://www.biochar.ac.uk/standard_materials.php; Accessed 07/02/2017). To ensure that particle size was small enough for inclusion in assays and to avoid gross differences between biochars, the material used in the assay was the fraction that passed through a 2 mm screen.

2.2. Experimental design

A 2 (biochar inclusion) × 2 (process temperature) × 5 (biomass source) factorial design was used where the factors were: biochar addition (10 or 100 g biochar/kg substrate fresh weight); biochar process temperature (550 or 700 °C) and biomass source (*Miscanthus* straw, oil seed rape straw, rice husk, soft wood pellets or wheat straw). Each of the 20 individual treatments was incubated in triplicate in each replicate (week of experiment). Within each replicate, control samples which contained substrate but no added biochar and blank samples without substrate or biochar were also included in triplicate giving a total of 66 incubations on each replicate. There were a total of four replicates of the above carried out at 14 day intervals.

Table 1
Composition of biochars manufactured at different peak temperatures and prepared from different biomass sources (g/kg DM unless stated otherwise).

Source	Miscanthus straw pellets		Oil seed rape straw pellets		Rice husks		Soft wood pellets		Wheat straw pellets	
Temperature (°C)	550	700	550	700	550	700	550	700	550	700
Dry matter (g/kg)	982	988	974	964	985	985	985	990	986	978
Ash	122	116	195	219	479	473	125	189	213	238
pH	9.77	9.72	9.78	10.40	9.71	9.81	7.91	8.44	9.94	10.00
C	754	792	689	677	487	473	855	902	683	690
H	24	13	18	11	12	6	28	18	21	12
O	92	70	89	78	25	21	104	60	69	53
N	8	10	16	13	10	9	< 1	< 1	14	13
P	2	8	3	3	1	5	< 1	< 1	1	3
K	10	26	29	30	4	6	2	3	16	15
Surface area (m^2/g)	34	37	16	22	20	42	26	162	26	23
Volatile matter	116	77	164	252	75	50	142	67	106	74

Data reproduced from UK Biochar Research Centre (http://www.biochar.ac.uk/standard_materials.php; Accessed 07/02/2017).