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Research paper

Antagonistic effects on biogas and methane output when co-digesting cattle and pig slurries with grass silage in *in vitro* batch anaerobic digestion

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ABSTRACT

Anaerobic co-digestion of contrasting substrates can result in synergistic or antagonistic effects on methanogenesis. Biogas and methane yields of the mixtures of cattle slurry (CS1 and CS2) or pig slurry with grass silages (GS1 and GS2) were measured using *in vitro* anaerobic batch digesters, and synergistic and antagonistic effects were investigated. Slurries and silages were incubated as individual substrates or as part of binary mixtures (slurry:silage mass ratios of volatile solids (*VS*) of 1:0, 0.75:0.25, 0.5:0.5, 0.75:0.25 and 0:1). The biogas yields of CS1, CS2, pig slurry, GS1 and GS2 were 405.9, 380.4, 550.8, 673.7 and 610.6 $L\,kg^{-1}$ of *VS*, respectively while the corresponding methane yields were 269.1, 246.4, 380.1, 427.7 and 359.0 $L\,kg^{-1}$ of *VS*. The sequential replacement of either cattle slurry by either grass silage caused a progressive increase in biogas and methane yields, but there was not as clear-cut increase when pig slurry was replaced by grass silages. The methane yield for slurry and silage mixtures displayed non-linear blending and the maximum effect, which was always antagonistic, was at a 0.5:0.5 mass ratio of *VS*, and ranged from 5.7-7.6 % below the yields predicted from mono-digestion of individual substrates.

1. Introduction

The on-farm anaerobic digestion (AD) plants in some European countries utilize energy crops such as maize but the Irish climate limits reliable economic production of maize. However, cattle slurry, pig slurry and grass silage are three major potential AD substrates in Ireland. For example, the 6.6 million cattle and 1.6 million pigs [1] produce about 36 Mt and 2.5 Mt [2] of slurry per year, respectively. Over 90 % of the Irish agricultural land is under grassland [3], and its relatively high yield results in an estimate of 1.7 Mt of grass total solids per year in excess of livestock requirements. With intensive grassland management, there is potential to increase this to 12.2 $Mt\,y^{-1}$ [4].

Cattle slurry usually supports a lower methane yield compared to energy crops or grass silage as the livestock have already utilised much of the more easily digestible organic components in the feeds [5]. When expressed on a volatile solids (*VS*) basis, pig slurry can produce higher methane yields than cattle slurry, but pig slurry often has a lower *VS* mass fraction [5–8]. Furthermore, a challenge with AD of grass silage relates to a risk of process imbalance when mono-digested over an extended duration at high organic loading rates [9]. Thus, the co-digestion of animal slurry (rich source of trace elements and stabilising buffering capacity) with grass silage (more easily digestible organic content, borderline trace elements concentrations and marginal buffering capacity) could complement each other and greatly enhance the longevity of stable and productive AD.

The anaerobic co-digestion of contrasting substrates can result in synergistic (i.e. the mixture produces more methane than the arithmetically calculated yield from individual substrates) or antagonistic (the mixture produces less yield than predicted from individual substrates) effects. The synergistic effects are usually due to the addition of complementary elements to the co-digestion mixture, such as additional alkalinity, trace elements, nutrients or enzymes that a substrate by itself

Abbreviations: AA, Acetic acid; AD, Anaerobic digestion; ADF, Acid detergent fibre; ADL, Acid detergent lignin; AFBI, Agri-Food and Biosciences Institute; AR, Agricultural residue; AS, Animal slurry; BA, Butyric acid; BMP, Biochemical methane potential; BS, Beef cow slurry; C:N, Carbon:Nitrogen; CD, Cow dung; CF, Cow faeces; CM, Cow manure; CP, Crude protein; CS1, Cattle slurry 1; CS2, Catttle slurry 2; CSTR, Continuously stirred tank reactor; DM, Dairy cow manure; DS, Dairy cow slurry; Eth, Ethanol; G, Grass; GS, Grass silage; GS1, Grass silage 1; GS2, Grass silage 2; k, First order decay constant; LA, Lactic acid; NA, Not available; NDF, Neutral detergent fibre; NH_3-N, Ammonia-nitrogen; NLB, Non-linear blending; OLR, Organic loading rate; P, Level of significance; PM, Pig manure; PS, Pig slurry; T_{50}, Time taken to produce 50 % of the gas production (Half-life); TS, Total solids; TSD, Total solids digestibility; U, Maximum methane or biogas production rate; VFA, Volatile fatty acids; VS, Volatile solids; WSC, Water-soluble carbohydrates; λ, Lag phase and λ_T: Exponential phase

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Table 1
Summary of methane yields from published comparisons of animal slurry with grass or grass silage.

Substrates	Co-digestion ratio	Methane yield (L kg^{-1})	Reactor	Operating parameters	NLB (%)
Dairy cow slurry (DS) and grass silage (GS)	DS:GS	361*	CSTR	OLR 0.7	–
[16]	1:0	493*		kg m^{-3} d^{-1} at 35 °C	−7
Perennial ryegrass (*Lolium perenne*), cocksfoot (*Dactylis glomerata*) and meadow	0.33:0.67	613*			–
foxtail (*Alopecurus pratensis*) silage	0:1				
Pig manure (PM) and grass (G)	PM:G	257	Batch	35 °C	–
[17]	1:0	314			−3
Dried green para grass (*Branchiria mutica*); inoculum from pig farm digester	0.75:0.25	383			−2
	0.5:0.5	453			−1
	0.25:0.75	522			–
	0:1				
Dairy cow slurry (DS) and grass silage (GS)	DS:GS	239	Batch	37 °C	–
[13]	1:0	250			−8
First cut perennial ryegrass (*Lolium perenne*) silage	0.8:0.2	273			−11
	0.6:0.4	308			−4
	0.5:0.5	321			−5
	0.4:0.6	345			−7
	0.2:0.8	400			–
	0:1				
Cow dung (CD) or pig manure (PM) and grass (G)	CD:G	68	Batch	53 °C	–
[18]	1:0	150			−14
	0.67:0.33	125			−38
	0.84:0.16	226			–
	0:1	117			–
	PM:G	149			−24
	1:0	125			−40
	0.73:0.27				
	0.84:0.16				
Cow manure (CM) and grass (G)	CM:G	94	CSTR	OLR 1.8	–
[19]	1:0	149		kg m^{-3} d^{-1} at 25 °C	+173
Totora (*Schoenoplectus tatora*)	0.5:0.5	15			–
	0:1				
Cow faeces (CF) and grass (G)	CF:G	111	Batch	35 °C	–
[20]	1:0	115			+1
Salt water cord grass (*Spartina alterniflora*)	0.875:0.125	122			+4
	0.75:0.25	143			+15
	0.5:0.5	177			+35
	0.25:0.75	161			+20
	0.125:0.875	138			–
	0:1				
Dairy cow slurry (DS) and grass (GR)	DS:GR	89	Batch	37 °C	–
[21]	1:0	134			+18
Dried switch grass	0.75:0.25	155			+39
	0.5:0.5	143			+33
	0.25:0.75	131			–
	0:1				
Beef cow slurry (BS) and grass silage 1 (GS1) or grass silage 2 (GS2)	BS: GS1	282	Batch	37 °C	–
[14]	1:0	304			+4
Perennial ryegrass (*Lolium perenne*) silage from grass harvested at two growth stages	0.75:0.25	309			+3
	0.5:0.5	310			0
	0.25:0.75	318			–
	0:1	304			+7
	BS: GS2	304			+7
	0.75:0.25	294			+3
	0.5:0.5	286			–
	0.25:0.75				
	0:1				
Dairy cow manure (DM) and grass silage (GS)	DM:GS	250	CSTR	OLR 2	NA
[22]	0.4:0.6	268		kg m^{-3} d^{-1} at 35 °C	
75 % timothy (*Phleum pratense*), 25 % meadow fescue (*Festuca pratensis*) harvested at	0.3:0.7	178			
early flowering stage	0.2:0.8	143			
	0.1:0.9	151			
	0:1				
Dairy cow manure (DM) and grass silage (GS)	DM:GS	183	CSTR	OLR 2	NA
[23]	0.7:0.3			kg m^{-3} d^{-1} at 35 °C	
75 % timothy (*Phleum pratense*), 25 % meadow fescue (*Festuca pratensis*)					
Dairy cow manure (DM) and agricultural residue (AR)	DM:AR	175	CSTR	OLR 3	NA
[24]	0:1	181		kg m^{-3} d^{-1} at 35 °C	
30 % Clover, 40 % grass, 30 % wheat straw	0.3:0.7				

(*continued on next page*)