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Global beef cattle methane emissions: yield prediction by cluster and meta-analyses

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Table S1. Beef studies (n = 109) that were either: excluded due to lack of meta-data or doubts about data quality; had multiple control methane yield (MY) values (rows); or were screened in after K mean cluster analyses based on standardised number of animals (N), liveweight (LW) and MY value

Reference	Data issues	Multi-controls	#K means Cluster
Bayaru et al. (2001)	x		
Beauchemin and McGinn (2005)		x	3
Beauchemin and McGinn (2006)		x	3
Beauchemin et al. (2007)		x	3
Benz and Johnson (1982)	x		
Berchielli et al. (2003)	x		
Berra et al. (2008).	x		
Birkelo et al. (1986)	x		
Boadi et al. (2004)			3
Boadi et al. (2002a)		x	3
Boadi et al. (2002b)		x	3
Boland et al. (2013).			3
Brown et al. (2011)	x		
Cammell et al. (1986)	x		
Carmean and Johnson (1990)	x		
Chaves et al. (2006)			3
Chung et al. (2013)		x	2
Chung et al. (2011)	x		
Chung et al. (2010)	x	x	
Cole and McCroskey (1975)	x		
Cooprider et al. (2011)	x		
Delfino et al. (1988)	x		
Denman et al. (2007)			3
DeRamus et al. (2003)	x		
Doreau et al. (2011)		x	2
Estermann et al. (2002)	x		
Eugene et al. (2009)			2
Eugene et al. (2011)		x	2
Fitzsimons et al. (2013)		x	2
Foley et al. (2009)	x	x	1
Goopy and Hegarty (2004)	x		
Guan et al. (2006)		x	3
Gutierrez-Banuelos et al. (2007)	x		
Haaland et al. (1981)	x		
Hales et al. (2013)	x	x	
Han et al. (1997)	x		
Harper et al. (2002)	x		
Hart et al. (2009)	x		
Hart et al. (2008)	x		

Hegarty et al. (2007)			3
Hellwing et al. (2012).	x		
Herd et al. (2014)			1
Hironaka et al. (1996)		x	3
Holmes et al. (1978)	x		
Hulshof et al. (2012)			3
Hunerberg et al. (2013)			2
Itabashi et al. (2000).	x	x	
Johnson et al. (1994)	x		
Jones et al. (2011)	x		
Jonker et al. (2014)		x	2
Jordan et al. (2006)		x	2/3
Kawashima et al. (2007)	x		
Kennedy and Charmley (2012)		x	3
Kongmun et al. (2011)	x		
Kurihara et al. (1999)	x		
Lila et al. (2004)	X		
Lila et al. (2005)	x	x	
Lovett et al. (2003)		x	2
Malik and Singhal (2008)			3
Malik and Singhal (2009)	x		
Martin et al. (2008)	x	x	
Mathison et al. (1991)	x		
McCaughey et al. (1997)		x	3
McCaughey et al. (1999)		x	2
McCrabb et al. (1997)	x		
Mc Geough et al. (2009)		x	2
McGinn et al. (2009)			2
McGinn et al. (2004)	x		
Mehra et al. (2006)	x		
Micol et al. (2007)	x		
Mohammed et al. (2004a)	x		
Mohammed et al. (2004b)	x		
Mwenya et al. (2004)	x	x	
Mwenya et al. (2005)	x		
Neto et al. (2009)			2/3
Newbold et al. (1996)		x	2
Nishida et al. (2007)	x	x	
Nkrumah et al. (2006)	x		
O'Kelly and Spiers (1992)		x	2/3
Oliveira et al. (2007)		x	3
Omar (2004)	x		
Pattanaik et al. (2003)		x	3
Pedreira et al. (2013).	x		
Pelve et al. (2012)	x		
Pen et al. (2006)	x		

Perry and Weatherly (1976)	x		
Pinares-Patino et al. (2003)		x	2
Pinares-Patino et al. (2007)	x	x	
Plascencia et al. (1999)	x		
Popova et al. (2011)	x		
Possenti et al. (2008)		x	2
Purnomoadi et al. (2009)	x		
Richmond et al. (2015)		x	2/3
Rooke et al. (2014)		x	2/3
Rumpler et al. (1986)	x		
Salinas-Chavira et al. (2009)	x		
Santoso et al. (2003)	x	x	
Staerfl et al. (2012)		x	3
Thornton and Owen (1981)	x		
Tiwari et al. (2000)	x		
Tomkins and Hunter (2004)		x	3
Tomkins et al. (2009)		x	2/3
Velazco et al. (2014)		x	2/3
Velazco et al. (2016)		x	2/3
Wedegaertner and Johnson (1983)	x		
Whitelaw et al. (1984)	x		
Yaremcio et al. (1991)		x	3
Zhang et al. (2007)	x		
Zinn (1986)	x		
Number 109	65	42	44

#Cluster number = IfMin(((:z_N - 0.996) / 0.1199)^2 + ((:z_LW - 0.366) / 0.1860)^2 + ((:z_MY - 0.518) / 0.1878)^2 = 1,

((:z_N - 0.040) / 0.1199)^2 + ((:z_LW - 0.551) / 0.1860)^2 + ((:z_MY - 0.650) / 0.1878)^2 = 2,

((:z_N - 0.0308) / 0.1199)^2 + ((:z_LW - 0.373) / 0.1860)^2 + ((:z_MY - 0.382) / 0.1878)^2 = 3)

Cluster means from Table 2b.

z_N is the normalised N value, z_LW is the normalised LW value, z_MY is the normalised MY value (see text).

Table S2. Details of references included in the meta-analyses

References	Country	Method	Sex:stage	Feed details	MY g/kg DMI
Beauchemin and McGinn (2005)	Canada	chamber	heifer	70% corn silage, 18% corn grain, 12 % supplement	25
Beauchemin and McGinn (2005)	Canada	chamber	heifer	70% corn silage, 18% corn grain, 12 % supplement	9
Beauchemin and McGinn (2005)	Canada	chamber	heifer	70% barley silage, 25% barley grain, 5% supplement	24
Beauchemin and McGinn (2005)	Canada	chamber	heifer	70% forage 30% barley concentrate; grain: 70% corn concentrate 30%	13
Beauchemin and McGinn (2006a)	Canada	chamber	heifer	70% forage 30% barley concentrate; grain: 70% corn concentrate 30%	21
Beauchemin and McGinn (2006a)	Canada	chamber	heifer	forage	20
Beauchemin and McGinn (2006b)	Canada	chamber	spayed heifer	75% barley silage, 19% steam-rolled barley, 6% supplement	22
Beauchemin et al. (2007a)	Canada	chamber	heifer	barley silage, steam rolled barley, supplements	18
Beauchemin et al. (2007a)	Canada	chamber	heifer	barley silage, steam rolled barley, supplements	18
Beauchemin et al. (2007a)	Canada	chamber	heifer	barley silage, steam rolled barley, supplements	15
Beauchemin et al. (2007b)	Canada	chamber	heifer	70% forage	19
Beauchemin et al. (2007b)	Canada	chamber	heifer	70% forage	19
Boadi et al. (2002)	Canada	*SF6	steers	alfalfa and brome grass	21
Boadi and Wittenburg (2002)	Canada	SF6	heifer	legume/grass hay, restricted feeding	22
Boadi and Wittenburg (2002)	Canada	SF6	heifer	grass hay, ad lib feeding	23
Boadi and Wittenburg (2002)	Canada	SF6	heifer	legume/grass hay, ad lib feeding	21
Boadi and Wittenburg (2002)	Canada	SF6	heifer	high forage 41.8% barley silage 41.7% barley grain; low forage 11.5 %	23
Boadi and Wittenburg (2002)	Canada	SF6	heifer	silage	25
Boadi et al. (2004)	Canada	SF6	steers	83.5% grain	8
Boland et al. (2013)	Ireland	SF6	heifers	perennial ryegrass pasture	19
Chaves et al. (2006)	Canada	SF6	heifer	grass or alfalfa pasture	31
Chung et al. (2010)	Canada	SF6	cows	50% barley silage, 19.5% barley grain, 30.5% pellets	18
Chung et al. (2010)	Canada	SF6	cows	50% barley silage, 19.5% barley grain, 30.5% pellets	16
Chung et al. (2011)	Canada	SF6	cows	hay forage : concentrate 50 : 50	19
Chung et al. (2011)	Canada	SF6	cows	silage forage : concentrate 50 : 50	18
Chung et al. (2011)	Canada	SF6	cows	silage	20
Chung et al. (2011)	Canada	SF6	cows	silage with linseed	19

Chung et al. (2013)	Canada	chamber	heifer	fresh cut legumes	24
Chung et al. (2013)	Canada	chamber	heifer	both legumes as hay	23
Denman et al. (2007)	Australia	chamber	steers	Long chopped Rhodes grass + 1kg/d grain pellets+10g cotton seed meal	12
Doreau et al. (2011)	France	SF6	bulls	63% corn silage, 21% ground corn grain, 16% soybean meal	20
Doreau et al. (2011)	France	SF6	bulls	49% hay, 41% ground corn, 10% soybean meal	10
Eugene et al. (2009)	France	SF6	bulls	concentrate, barley straw	24
Eugene et al. (2011)	France	SF6	bulls	barley straw, concentrate	23
Eugene et al. (2011)	France	SF6	bulls	barley straw, concentrate	28
Eugene et al. (2011)	France	SF6	bulls	barley straw, concentrate	36
Foley et al. (2009)	Ireland	SF6	heifer	silage + concentrate	26
Foley et al. (2009)	Ireland	SF6	heifer	silage + concentrate	24
Fitzsimons et al. (2013)	Ireland	SF6	heifer	grass silage	36
Fitzsimons et al. (2013)	Ireland	SF6	heifer	grass silage	36
Fitzsimons et al. (2013)	Ireland	SF6	heifer	grass silage	38
Guan et al. (2006)	Canada	SF6	steers	10.8% alfalfa silage, 75.2% corn silage, 12.9% canola meal, 1.1% m mix	22
Guan et al. (2006)	Canada	SF6	steers	10.8% alfalfa silage, 75.2% corn silage, 12.9% canola meal, 1.1% m mix	23
Guan et al. (2006)	Canada	SF6	steers	22.7% alfalfa silage, 8.3% corn silage, 67.9% barley grain, 1.1% m mix	20
Guan et al. (2006)	Canada	SF6	steers	22.7% alfalfa silage, 8.3% corn silage, 67.9% barley grain, 1.1% m mix	20
Hart et al. (2009)	UK	SF6	heifer	fresh herbage ad lib	26
Hegarty et al. (2007)	Australia	SF6	steers	TMR based on barley and roughage	15
Herd et al. (2014)	Australia	chamber	bulls	roughage	23
Herd et al. (2014)	Australia	chamber	heifer	roughage	23
Hironaka et al. (1996)	Canada	chamber	steers	chopped alfalfa hay	23
Hironaka et al. (1996)	Canada	chamber	steers	chopped alfalfa hay	17
Hironaka et al. (1996)	Canada	chamber	steers	chopped alfalfa hay	20
Hironaka et al. (1996)	Canada	chamber	steers	chopped alfalfa hay	21
Hunerber et al. (2013)	Canada	chamber	heifer	Barley silage, barley grain, canola meal and supplements	22
Hunerberg et al. (2013)	Canada	chamber	heifer	Barley silage, barley grain, canola meal and supplements	24
Hunerberg et al. (2013)	Canada	chamber	heifer	Barley silage, barley grain, canola meal and supplements	21
Hulshof et al. (2012)	Brazil	SF6	steers	frsh chopped sugarcane (60%), concentrate (40%)	13

Itabashi et al. (2000)	Japan	chamber	steers	sorgum silage + vitamin mix	15
Jonker et al. (2014)	New Zealand	chamber	heifer	mixed ration	24
Jonker et al. (2014)	New Zealand	chamber	heifer	mixed ration	25
Jonker et al. (2014)	New Zealand	chamber	heifer	mixed ration	25
Jonker et al. (2014)	New Zealand	chamber	heifer	mixed ration	24
Jonker et al. (2014)	New Zealand	chamber	heifer	mixed ration	24
Jordan et al. (2006a)	Ireland	SF6	heifer	50% concentrate and 50% forage	31
Jordan et al. (2006a)	Ireland	SF6	heifer	50% concentrate and 50% forage	33
Jordan et al. (2006b)	Ireland	SF6	bulls	90% concentrate (barley based) 10% barley straw	11
Jordan et al. (2006b)	Ireland	SF6	bulls	90% concentrate (barley based) 10% barley straw	15
Jordan et al. (2006c)	Ireland	SF6	heifer	50% concentrate and 50% forage	37
Jordan et al. (2006c)	Ireland	SF6	heifer	50% concentrate and 50% forage	34
Jordan et al. (2006c)	Ireland	SF6	heifer	50% concentrate and 50% forage	30
Kennedy and Charmley (2012)	Australia	chamber	steers	Spear grass L1 923	20
Kennedy and Charmley (2012)	Australia	chamber	steers	Spear grass L2 924	19
Kennedy and Charmley (2012)	Australia	chamber	steers	Buffel grass H 886	22
Kennedy and Charmley (2012)	Australia	chamber	steers	Buffel grass M/H 893	22
Kennedy and Charmley (2012)	Australia	chamber	steers	Buffel grass M 900	21
Kennedy and Charmley (2012)	Australia	chamber	steers	Bisset grass M1 916	22
Kennedy and Charmley (2012)	Australia	chamber	steers	Bisset grass M2 891	19
Kennedy and Charmley (2012)	Australia	chamber	steers	Mitchell grass 896	17
Kennedy and Charmley (2012)	Australia	chamber	steers	Rhodes grass 909	19
Kennedy and Charmley (2012)	Australia	chamber	steers	Burgundy bean 887	16
Kennedy and Charmley (2012)	Australia	chamber	steers	Stylo 953	19
Kennedy and Charmley (2012)	Australia	chamber	steers	Lucerne 901	21
Kurihara et al. (1999)	Australia	chamber	heifer	roughage	31
Kurihara et al. (1999)	Australia	chamber	heifer	roughage	36
Kurihara et al. (1999)	Australia	chamber	heifer	mixed	22
Lovett et al. (2003)	Ireland	SF6	heifer	3 levels of forage:concentrate	24
Lovett et al. (2003)	Ireland	SF6	heifer	low concentrate: 65:35; high concentrate: 10:90	21

Malik and Singhal (2008)	India	SF6	calves	wheat straw : concentrate (60 : 40)	12
McCaughey et al. (1997)	Canada	SF6	steers	alfalfa, meadow bromegrass, Russian wild rye	13
McCaughey et al. (1997)	Canada	SF6	steers	alfalfa, meadow bromegrass, Russian wild rye	15
McCaughey et al. (1997)	Canada	SF6	steers	alfalfa, meadow bromegrass, Russian wild rye	13
McCaughey et al. (1997)	Canada	SF6	steers	alfalfa, meadow bromegrass, Russian wild rye	17
McCaughey et al. (1999)	Canada	SF6	cows	meadow bromegrass	25
McCaughey et al. (1999)	Canada	SF6	cows	legume	32
McGeough et al. (2009)	Ireland	SF6	steers	maize crop silage	22
McGeough et al. (2009)	Ireland	SF6	steers	grass silage	15
McGeough et al. (2009)	Ireland	SF6	steers	grass silage	26
McGinn et al. (2009)	Canada	SF6	steers	60% barley silage, 35% barley grain (or ddgs)	20
Neto et al. (2009)	Brazil	SF6	dry cows	Brachiaria brizantha Marandu hay	18
Neto et al. (2009)	Brazil	SF6	dry cows	Brachiaria brizantha Marandu hay	14
Newbold et al. (1996)	UK	chamber	steers	grass silage, low concentrate, 1xM	32
Newbold et al. (1996)	UK	chamber	steers	grass silage, low concentrate, 1xM	28
Newbold et al. (1996)	UK	chamber	steers	grass silage, low concentrate, 1.7xM	28
Newbold et al. (1996)	UK	chamber	steers	grass silage, low concentrate, 1.7xM	25
Newbold et al. (1996)	UK	chamber	steers	grass silage, high concentrate, 1xM	27
Newbold et al. (1996)	UK	chamber	steers	grass silage, high concentrate, 1xM	25
Newbold et al. (1996)	UK	chamber	steers	grass silage, high concentrate, 1.7xM	17
Newbold et al. (1996)	UK	chamber	steers	grass silage, high concentrate, 1.7xM	16
O'Kelly and Spiers (1992)	Australia	chamber	steers	Lucerne hay	10
O'Kelly and Spiers (1992)	Australia	chamber	steers	Lucerne hay	29
Oliveira et al. (2007)	Brazil	SF6	steers	Sorghum silage and corn/soybean concentrate	12
Oliveira et al. (2007)	Brazil	SF6	steers	Sorghum silage and urea concentrate	13
Pattanaik et al. (2003)	India	chamber	calves	maize and groundnut meal	17
Pattanaik et al. (2003)	India	chamber	calves	maize and cottonseed meal	19
Pattanaik et al. (2003)	India	chamber	calves	maize and bone meal	18
Pelve et al. (2012)	Sweden	SF6	dry cows	round baled forage	26
Pinares-Patino et al. (2003)	France	SF6	early-pregnant	timothy pasture	25

Pinares-Patino et al. (2003)	France	SF6	cows	timothy pasture	25
Pinares-Patino et al. (2003)	France	SF6	cows	timothy pasture	25
Pinares-Patino et al. (2003)	France	SF6	cows	timothy pasture	25
Popova et al. (2011)	France	SF6	bulls	fattening diet	36
Possenti et al. (2008)	Brazil	chamber	steers	grass hay and leucaena	19
Possenti et al. (2008)	Brazil	chamber	steers	grass hay and leucaena	18
Richmond et al. (2015)	UK	SF6	steers	Lowland improved grassland	21
Richmond et al. (2015)	UK	SF6	steers	Upland semi-natural grassland	22
Rooke et al. (2014)	UK	chamber	steers	7.5% forage:92.5% grain	13
Rooke et al. (2014)	UK	chamber	steers	48% forage:52% grain	21
Rooke et al. (2014)	UK	chamber	steers	7.5% forage:92.5% grain	14
Rooke et al. (2014)	UK	chamber	steers	48% forage:52% grain	22
Staerfl et al. (2012)	Switzerland	chamber	bulls	maize silage, concentrate	18
Staerfl et al. (2012)	Switzerland	chamber	bulls	maize silage, concentrate	24
Staerfl et al. (2012)	Switzerland	chamber	bulls	maize silage, concentrate	26
Staerfl et al. (2012)	Switzerland	chamber	bulls	maize silage, concentrate	24
Staerfl et al. (2012)	Switzerland	chamber	bulls	silage, concentrate	27
Tomkins and Hunter (2004)	Australia	chamber	steers	feedlot diet	5
Tomkins and Hunter (2004)	Australia	chamber	steers	feedlot diet	2
Tomkins and Hunter (2004)	Australia	chamber	steers	feedlot diet	1
Tomkins et al. (2009)	Australia	chamber	steers	grain based diet	12
Tomkins et al. (2009)	Australia	chamber	steers	grain based diet	23
Tomkins et al. (2009)	Australia	chamber	steers	grain based diet	19
Tomkins et al. (2009)	Australia	chamber	steers	grain based diet	20
Velazco et al. (2014)	Australia	GEM	steers	festuca, dactylis, paspalum	23
Velazco et al. (2014)	Australia	GEM	heifers	festuca, dactylis, paspalum	25
Velazco et al. (2016)	Australia	chamber	cows	lucerne/oaten chaff + pellet	24
Velazco et al. (2016)	Australia	GEM	cows	lucerne/oaten chaff + pellet	23
Velazco et al. (2016)	Australia	GEMwater	cows	lucerne/oaten chaff + pellet	11
Velazco et al. (2016)	Australia	chamber	steers	lucerne/oaten chaff + pellet	22

Velazco et al. (2016)	Australia	GEM	steers	lucerne/oaten chaff + pellet	24
Velazco et al. (2016)	Australia	GEMwater	steers	lucerne/oaten chaff + pellet	23
Yaremcio et al. (1991)	Canada	chamber	steers	whole barley concentrate	9
Yaremcio et al. (1991)	Canada	chamber	steers	rolled barley concentrate	10

*SF6- sulphur hexafluoride tracer, GEM- Greenfeed emission monitoring units, GEM water – water, not feed pellets used.

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