A Review of Greenhouse Gas Emissions from the Use of Brassica and Fodder Beet Forages on New Zealand Farms

BC Thomson, KJ Hammond and PD Muir

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Prepared by: BC Thomson[1], KJ Hammond[2] and PD Muir[1]*

[1]On-Farm Research, PO Box 1142, Hastings, New Zealand

[2]AgResearch Grasslands Research Centre, Tennent Drive, Private Bag 11008, Palmerston North 4442, New Zealand

** Corresponding author: Paul Muir: paul@on-farm.co.nz; phone +64 6 8748757*

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1 RECOMMENDATIONS

- ENTERIC METHANE EMISSION: Compared to ryegrass/white clover pastures, brassica crops appear to result in a 30% decrease in enteric methane emitted per kg dry matter intake (DMI). This is likely to be at least partially related either directly or indirectly to brassica's lower fibre and higher non-structural carbohydrate contents. The majority of the New Zealand trials have compared rape (a high quality feed) with a low quality ryegrass diet. This makes it difficult to extrapolate the results over all brassicas and all pasture diets.
- NITROUS OXIDE EMISSION: There is insufficient quality data available on the effect of brassicas on nitrous oxide (N_2O) emissions from grazing systems. Reported experiments have confounding variables, such as the application of urine (or faeces) from brassica-fed animals on soils growing conventional pasture (or vice versa of urine from pasture-fed animals applied to soils growing brassicas). Further research should focus on:
    - Better information on how the EF3 factors vary under the different systems using brassicas on farm.
    - Obtaining additional N_2O (and methane) emission data from fodder beet, given the rapid increase in farm area being sown of this high quality and high yielding crop.
- BRASSICA AND FODDER BEET AS MITIGATION FEEDS: Assuming the area occupied in New Zealand by brassica crops is 250,000 ha, with an average yield of 10 tonne DM/ha, producing 2.5 million tonnes of DM annually and an utilisation of 80%, 3.9% of total DMI by New Zealand farmed ruminants is likely to obtained from brassica crops. Assuming each kg of DMI produces 21.4 g of methane, 2 million tonnes of utilised brassica DM will produce 428 tonnes of methane. Assuming that feeding ruminant livestock brassicas will reduce methane emissions by 30%, this will consequentially reduce methane output from farmed ruminants by 12,840 tonnes (or 321,000 tonnes of CO_2-equivalents). If the fertiliser costs are excluded (these are accounted for elsewhere) the agricultural footprint (crop residues and fuel) from growing 2.5 million tonnes of brassica will result in 125,400 tonne of CO_2-equivalent over and above that of the equivalent pasture. This suggests that there will be a net benefit of 195,600 tonnes of CO_2-equivalents from feeding forage brassicas. This assumes all brassica reduce methane in a similar way to forage rape. There is, however,

little reliable data available on the amounts of the different types of brassicas grown and the data on the methane reduction from different types of brassicas is limited. Due to these two deficiencies the calculation on the improvement in methane production from farmed ruminants can only be done on the data available and thus is likely to overestimate the reduction in methane due to feeding brassicas. There is insufficient data to extrapolate the N_2O research to brassicas nationally. For there to be a benefit in including brassicas in the model there needs to be a demonstrable effect on methane and N_2O emissions. The gaps in the current data include

- Information on the amounts and yields of various types of brassica and fodder beet fed in New Zealand
- The level of feeding used i.e. maintenance or above for various stock classes under the different systems.
- Whether different species of brassica have different effects on methane production
- The emission factors (EF) of the different plant species determined under the conditions where the various brassicas are used e.g. strip grazed in the middle of winter verses mob grazed in summer.
- Better lifecycle data analysis on the costs involved whether they be as direct agricultural costs or costs picked up by other industries e.g. a large increase in fertiliser requirements.

2 EXECUTIVE SUMMARY

Brassicas (represented mainly by forage rape, kale, swede and turnip) and fodder beet are widely used in New Zealand grazing systems due to their high DM yield and high nutritional value compared to conventional perennial ryegrass/white clover pastures. Brassica and fodder beet forages are commonly used in New Zealand during periods of feed shortage through the summer, autumn and winter; to supplement periods of low pasture quality; to finish stock; as a summer-safe feed; and often to control weeds prior to pasture renewal. The aim of this review was to assess available literature on the effects of feeding brassica and fodder beet forages to livestock on methane and nitrous oxide (N_2O) emissions. The focus of reducing one pollutant, such as the more efficient transfer of dietary nitrogen (N) into milk or meat and reduction of N excretion into faeces and urine and, therefore, N_2O emission, may have implications for emissions of other pollutants, such as methane arising from the fermentation of feedstuffs within the ruminant forestomach. Thus, when it comes to feeding brassica and fodder beet forages to ruminant livestock, the trade-off between enteric methane production and N excretion (and therefore N_2O emission) needs to be understood, both at the animal scale and at the whole farm level.

Summarising the available literature, brassicas are characterised by lower fibre (NDF; neutral detergent fibre) and higher non-structural carbohydrate concentrations, compared to traditional perennial ryegrass/white clover pastures. This marked difference in chemical composition may partly explain the average decrease of 30% in methane yield (g/kg dry matter intake [DMI]) across a range of studies. The effect of brassicas on N_2O emissions from grazing systems (as measured by using 'emission factors' e.g. EF3) is unclear. It is difficult to interpret the effect of brassicas on N_2O emissions in experiments with confounding variables, such as the application of urine (or faeces) from brassica-fed animals on soils growing conventional pasture (or vice versa of urine from pasture-fed animals applied to soils growing brassicas). There are many variables (including season, soil type, soil temperature, soil moisture, soil compaction, urine composition and volume applied etc.), that need to be accounted for in future experimentation. These factors are important as generally brassicas are used as a summer feed when the ground is warm and dry or strip grazed in winter when the soils are wet and cold and there is the possibility of pugging.

The limited data on the effects of feeding brassicas on N_2O emissions together with the limited data on the amounts, yields and times of the year different brassicas are grown currently restricts our ability to assess the value of including brassicas in the New Zealand Inventory model.

3 INTRODUCTION

In New Zealand, methane accounts for 37.4% of total anthropogenic greenhouse gas (GHG) emissions with 85% of this from enteric fermentation in the digestive tracts of grazing ruminants (Sun et al., 2015). Enteric methane is formed mainly in the rumen from hydrogen generated by rumen microbes when they ferment feed ingested by the animal. Equally as important is nitrous oxide (N_2O), with emissions from agricultural soils representing 21.5% of all agricultural GHG emissions, or 10.4% of national GHG emissions (Ministry for the Environment, 2010). The largest source of N_2O in animal agriculture is from animal excreta, recycling nitrogen (N) inputs from fertiliser and biological N fixation within the soil-plant-animal system (Clark et al., 2005).

Numerous reviews have concluded that nutritional manipulation holds considerable promise as a mitigation option for ruminant GHG emissions. Identifying feeds that result in lower GHG emissions for the same level animal production may lead to farming systems that have low GHG production (Sun et al., 2015). In New Zealand, ruminant livestock production is almost exclusively pasture-based and aligned to seasonal pasture supply, with spring lambing/calving and supplementary feeding on a restricted basis (Clark and Woodward, 2007, Gibbs et al., 2015). This makes nutritional GHG mitigation options limited. Forage-based mitigation tools would be most easily incorporated into New Zealand's pastoral agriculture by identifying forage species already in use.

A possible GHG mitigation option for ruminant livestock systems is the use of brassica (*Brassicaeceae)* and fodder beet (*Beta vulgaris*) forages which are gaining popularity in New Zealand farming systems. Over recent years, New Zealand Agricultural Statistics indicate that the land area of forage brassica grown has shown a modest increase from 222,877 ha in 2009 to 246,528 ha in 2012. It is estimated that about 40% of the area cultivated by brassica forage is represented by kale (*Brassica oleracea* spp. *acephala*), swede (*Brasica napus* spp. *napobrassica)* and bulb turnip (*Brassica rapa* syn. B. *campestris*) for the dairy industry, while 60-70% is kale, swede, rape (*Brassica napus* spp. *biennis*), bulb and leafy turnip used in winter, summer and autumn for the sheep, beef and deer industries (Sun et al., 2016). Fodder beet has also rapidly increased in hectares (ha) sown over the past 10 years, largely driven by advances in agronomy and cost effective systems for feeding. Gibbs (2016) estimated from seed sales that the area sown in fodder beet has increased from 100 ha in 2006 to about 15,000 ha in 2014.

Brassica and fodder beet forages are reported to be 'game changers' for New Zealand's ruminant-based pastoral system. These crops have opened the potential for ruminant livestock production to be enhanced in seasons of lower pasture availability and quality (notably winter and summer). Forage brassicas have become New Zealand's most widely cultivated crop and are mainly used as a means of carrying a bulk of high quality feed into the summer (e.g. forage rape) or into the winter (e.g. kale or turnips) for grazing livestock. Generally, brassicas have a high dry matter digestibility (DMD; 0.81-0.89) and metabolisable energy (ME) (12.1-14.1 MJ/kg DM) content. Typical yields from brassicas are 2-8 t DM/ha for leafy turnip, 3-10 t/ha for rape, 2-12 t/ha for turnips, 5-20 t/ha for kale and 5-20/ha for swedes (de Ruiter et al., 2009). More recently, fodder beet has found favour as a high energy winter crop for dairy and beef cattle, with the potential to reduce the slaughter age of finishing beef cattle. Fodder beet's beneficial effects are the result of its nutritional value and cost. It has potential to be high yielding in winter (postulated to be 20-30 t DM/ha), have a high ME content (11-12 MJ/kg DM), and, once established, a low cost (4-10 c/kg DM) compared to silage, grain or lucerne (Gibbs, 2011).

Recent research has focused on brassica and fodder beet forages for their effect on enteric methane and N_2O emissions. The aim of this review is to evaluate whether evidence from published experiments result in a consistent reduction in methane and N_2O emissions from livestock fed these crops. It is important that GHG mitigation strategies are evaluated in a whole-system context, to ensure that reductions in one part of the system do not result in higher emissions elsewhere.

4 ENTERIC METHANE EMISSION

4.1 Summary of Experiments

Nine experiments have been summarised in this report; eight of these were conducted at the New Zealand Ruminant Methane Measurement Centre, in Palmerston North, New Zealand, with one experiment (experiment 8) undertaken at Ellinbank, Victoria, Australia. Details of the number of experiments, animal species, diet composition, dry matter intake (DMI), methane emission, DMD, acetate to propionate ratio (A:P) and rumen pH have been summarised here (Table 4.1). Diets covered in this section on methane emission included kale, rape, turnip (whole, leafy and bulb), swede and fodder beet, which were compared to control diets mainly being low quality ryegrass-based pasture, or one experiment (Experiment 8) which compared brassica to lucerne cubes/grain.

For all experiments summarised in this report, unless specified, methane emissions, expressed as methane production (g/d) or methane yield (g/kg DMI), were measured from individual sheep or cattle using respiration chambers which are described in detail by Pinares-Patiño et al. (2012). Methane emissions were estimated from grazing animals in Experiments 3 and 8 using the sulphur hexafluoride (SF_6) tracer technique as described by Berndt et al. (2014) and Deighton et al. (2014), respectively. Individual DMI were measured (based on feed offered and refused) within all experiments except for the SF_6 grazing trial of Experiment 3 where DMI was estimated using titanium dioxide (TiO_2) marker. Total tract DMD was measured in Experiments 1, 2, 3 (indoor trial only) and 4, based on total faecal collection over a minimum of 4 days. Experiments 1, 2, 4, 5 and 8 collected rumen digesta samples from individual animals and provided data on volatile fatty acid (VFA) acetate:proprionate (A:P) ratios. Rumen pH of digesta samples was provided from individual animals within Experiments 2, 4, 5 and 8. Table 4.2 summarises measurements of DMI, methane emission, DMD, A:P and rumen pH from all of the experiments described in Table 4.1.

A summary of chemical composition of control (pasture or lucerne cubes/grain), brassica forages (kale, rape, swede and turnip) and fodder beet diets fed to sheep and cattle across all experiments is given in Table 4.3. For all the diets fed within each experiment, wet chemistry was used to determine DM, crude protein (CP), hot water soluble carbohydrates (HWSC), pectin, neutral detergent fibre (NDF) and lignin concentrations. The readily fermentable carbohydrate to structural carbohydrate ratio (RFC:SC) was calculated as HWSC + pectin (RFC): NDF – lignin (SC). Diet composition data was not provided for Experiment 6, and HWSC and pectin were not measured in experiment 8 so these have not been included in Table 4.3.

Table 4.1 Summary of published experiments and number of observations when brassica forages (kale, rape, swede and turnip) and fodder beet were compared to control diets(pasture or lucerne cubes/grain)

Forage	Total no. of expts	No. of animal obs. per species		No. of animal obs. per CH_4 technique		No. of animal obs. (unless stated) per variable					
		Sheep	Cattle	RC	SF_6	Diet composition*	DMI	CH_4	DMD	A:P	Rumen pH
Brassica	**8**	**309**	**22**	**273**	**58**	**34**	**331**	**331**	**58**	**166**	**103**
Kale	1	9	0	9	0	1	9	9	5	10	0
Rape	8	234	22	198	58	27	256	256	41	108	75
Whole turnip	1	9	0	9	0	1	9	9	5	10	0
Leafy turnip	2	24	0	24	0	2	24	24	6	14	14
Bulb turnip	2	24	0	24	0	2	24	24	6	14	14
Swede	1	9	0	9	0	1	9	9	5	10	0
Fodder beet	**1**	**24**	**0**	**24**	**0**	**6**	**24**	**24**	**0**	**0**	**0**
Control Diet	**9**	**171**	**24**	**143**	**52**	**28**	**195**	**195**	**35**	**85**	**57**
Pasture	8	171	12	143	40	27	183	183	35	73	45
Lucerne cubes/grain	1	0	12	0	12	1	12	12	0	12	12
TOTAL	**9**	**504**	**46**	**440**	**110**	**68**	**550**	**550**	**93**	**251**	**160**

* For diet composition, obs. refers to number of forage samples analysed. DM content was not provided for experiment 3 and within this experiment diet composition was only provided for the SF_6 grazing study, no diet chemical data was provided for experiment 6, and missing from experiment 8 was dietary HWSC and pectin contents.

Expts, experiments; obs., observations; CH_4, methane emission; DMI, dry matter intake; DMD, total tract dry matter digestibility; A:P, acetate to propionate ratio; RC, respiration chamber; SF_6, sulphur hexafluoride tracer technique.

Experiment 1: Sun et al. (2012)

Experiment 2: Sun et al. (2013a, 2015c)
Experiment 3: Sun et al. (2013b)
Experiment 4: Sun et al. (2014a)
Experiment 5: Sun et al. (2014b, 2015a)
Experiment 7: Sun et al. (2015b)
Experiment 8:Williams et al. (2016)
Experiment 9: Pacheco et al. (unpublished)

Table 4.2 Summary of published experiments with sheep and cattle investigating brassica forages (kale, rape, swede and turnip) and fodder beet on dry matter intake (DMI), enteric methane (CH_4) emission, whole tract apparent DM digestibility (DMD), acetate:propionate (A:P) ratio and rumen pH and compared to control diets (pasture or lucerne cubes/grain)

	Obs.	Season	Animal species	CH_4 technique	DMI g/d	CH_4 g/d	CH_4 g/kg DMI	CH_4 change %*	DMD g/kg	A:P ratio	Rumen pH
Experiment 1											
Kale	9	Winter	Sheep	RC	887	17.0	19.8	-10	819	2.70	n/a
Rape	9	Winter	Sheep	RC	863	14.7	16.4	-25.5	809	2.55	n/a
Swede	9	Winter	Sheep	RC	839	13.3	16.9	-23.2	890	2.11	n/a
Turnip	9	Winter	Sheep	RC	861	18.0	20.6	-6	808	3.17	n/a
Ryegrass control	9	Winter	Sheep	RC	990	20.7	22.0	0.0	665	3.58	n/a
Experiment 2											
Rape	24	Winter	Sheep	RC	862	11.7	13.6	-30.3	800	2.75	n/a
Ryegrass control	18	Winter	Sheep	RC	792	15.4	19.5	0.0	646	3.88	n/a
Rape	24	Winter	Sheep	RC	896	16.0	17.8	-22.2	821	1.89	6.02
Ryegrass control	18	Winter	Sheep	RC	929	21.2	22.9	0.0	750	2.94	6.71
Experiment 3											
Rape	12	Winter	Sheep	RC	1120	13.2	11.3	-37.2	843	n/a	n/a
Ryegrass control	12	Winter	Sheep	RC	1058	19.2	18.0	0.0	789	n/a	n/a
Rape	12	Winter	Sheep	RC	1362	17.6	13.7	-31.8	838	n/a	n/a
Ryegrass control	12	Winter	Sheep	RC	1267	26.0	20.1	0.0	704	n/a	n/a
Rape	24	Winter	Sheep	SF_6	1053	13.3	14.0	-32.4	n/a	n/a	n/a
Ryegrass control	20	Winter	Sheep	SF_6	952	18.6	20.7	0.0	n/a	n/a	n/a
Rape	24	Winter	Sheep	SF_6	1266	18.6	15.4	-33.9	n/a	n/a	n/a
Ryegrass control	20	Winter	Sheep	SF_6	862	20.1	23.3	0.0	n/a	n/a	n/a
Experiment 4											
Primary rape	15	Summer	Sheep	RC	734	13.2	18.0	-15.0	784	2.86	6.20
Regrowth rape	14	Summer	Sheep	RC	827	15.3	18.6	-12.7	806	2.83	6.10
Leafy turnip	14	Summer	Sheep	RC	965	17.6	18.2	-14.6	775	2.43	6.00
Bulb turnip	14	Summer	Sheep	RC	914	22.0	24.1	+13.1	815	1.90	6.80
Ryegrass control	15	Summer	Sheep	RC	968	20.6	21.3	0.0	612	3.38	6.30
Experiment 5											
Rape	12	Winter	Cattle	RC	3850	49.0	12.6	-43.5	n/a	2.58	6.30
Ryegrass control	12	Winter	Cattle	RC	4070	90.8	22.3	0.0	n/a	2.36	6.95
Experiment 6											

Leafy turnip	10	Summer	Sheep	RC	908	12.5	14.0	-33.3	n/a	n/a	n/a
Bulb turnip	10	Summer	Sheep	RC	1042	17.3	16.7	-20.5	n/a	n/a	n/a
Rape (Bonar)	10	Summer	Sheep	RC	1036	19.0	18.4	-12.4	n/a	n/a	n/a
Rape (Titan)	10	Summer	Sheep	RC	860	15.4	18.8	-10.5	n/a	n/a	n/a
Radish	9	Summer	Sheep	RC	705	11.4	16.3	-22.4	n/a	n/a	n/a
Ryegrass control	9	Summer	Sheep	RC	687	14.3	21.0	0.0	n/a	n/a	n/a
Experiment 7											
Ryegrass control	n/a	Winter	Sheep	RC	806	18.1	22.5	0.0	n/a	n/a	n/a
25% rape	n/a	Winter	Sheep	RC	910	18.7	20.5	-8.9	n/a	n/a	n/a
50% rape	n/a	Winter	Sheep	RC	931	15.4	16.5	-26.7	n/a	n/a	n/a
75% rape	n/a	Winter	Sheep	RC	940	12.1	12.9	-42.7	n/a	n/a	n/a
100% rape	n/a	Winter	Sheep	RC	978	8.1	8.2	-63.6	n/a	n/a	n/a
Experiment 8											
Lucerne cubes/grain control	12	Summer	Cattle	SF_6	20800	436	21.0	0.0	n/a	3.32	6.61
41% Rape	10	Summer	Cattle	SF_6	20600	421	20.5	-2.4	n/a	2.85	6.60
Experiment 9											
Pasture control	12	Winter	Sheep	RC	922	18.1	19.6	0.0	n/a	n/a	n/a
75:25 FB:pasture	12	Winter	Sheep	RC	928	17.2	18.6	-5.4	n/a	n/a	n/a
Pasture control	12	Winter	Sheep	RC	877	17.6	20.1	0.0	n/a	n/a	n/a
90:10 FB:pasture	12	Winter	Sheep	RC	845	6.7	7.7	-61	n/a	n/a	n/a

* Change in methane yield from control feed
Experiment 1 Sun et al. (2012)
Experiment 2 Sun et al. (2013a, 2015c)
Experiment 3 Sun et al. (2013b)
Experiment 4 Sun et al. (2014a)
Experiment 5 Sun et al. (2014b, 2015a)
Experiment 6 Sun et al (2014c)
Experiment 7 Sun et al. (2015b)
Experiment 8 Williams et al (2016)
Experiment 9 Pacheco et al (unpublished)
Obs., number of observations; RC, respiration chamber; SF_6, sulphur hexafluoride tracer; n/a, not available; FB, fodder beet.

Table 4.3 Summary of diet composition, as determined by wet chemistry, for sheep and cattle fed control diets (pasture or lucerne cubes/grain) brassica forages (kale, rape, swede and turnip) and fodder beet

	n	Forage chemical composition (g/kg DM unless stated)									
		DM[1]	CP	HWSC	Pectin	NDF	Lignin	RFC:SC[2]	Nitrate-N[3]	Sulphur[3]	Sulphate[3]
Experiment 1											
Kale	1	141	167	173	80	201	57	1.76	0.10	8.5	4.4
Rape	1	126	193	196	89	234	63	1.67	0.48	6.1	2.3
Swede	1	94	162	301	69	176	51	3.11	0.48	5.6	2.4
Turnip	1	101	130	238	94	240	63	1.88	<0.10	6.9	2.8
Ryegrass control	1	176	150	106	10	536	30	0.23	<0.10	3.3	1.2
Experiment 2											
Rape	3	131	215	142	76	209	38	1.31	135	150	63
Ryegrass control	3	148	181	83	9	464	27	0.21	13	100	39
Rape	3	142	158	240	75	170	37	2.38	<7.1	100	28
Ryegrass control	3	198	160	123	11	445	17	0.31	15	90	34
Experiment 3											
Rape	4	n/a	213	200	86	137	31	2.70	n/a	n/a	n/a
Ryegrass control	4	n/a	238	73	12	528	26	0.17	n/a	n/a	n/a
Rape	4	n/a	212	203	71	147	26	2.26	n/a	n/a	n/a
Ryegrass control	4	n/a	238	66	11	470	29	0.17	n/a	n/a	n/a
Experiment 4											
Primary Rape	2	195	94	207	103	286	103	1.95	<7.1	172	99
Regrowth Rape	2	186	106	197	98	250	93	2.15	<7.1	185	116
Leafy turnip	2	122	180	145	90	227	64	1.63	66.3	283	155
Bulb turnip	2	108	120	244	78	212	94	2.94	19.4	173	93
Pasture control	2	247	174	71	29	505	62	0.24	<7.1	95	45
Experiment 5											
Rape	3	116	256	193	88	183	75	2.62	132	173	76
Pasture control	3	135	232	121	12	444	24	0.32	45	135	60
Experiment 6											
Leafy turnip		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Bulb turnip		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Rape (Bonar)		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Rape (Titan)		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Radish		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a

Ryegrass control		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Experiment 7											
Ryegrass control	1	136	228	73	12	518	20	0.17	n/a	n/a	n/a
25% Rape	1	125	253	92	31	434	30	0.61	n/a	n/a	n/a
50% Rape	1	116	278	111	50	351	40	1.04	n/a	n/a	n/a
75% Rape	1	106	303	130	69	267	49	1.47	n/a	n/a	n/a
100% Rape	1	99	328	149	88	183	59	1.91	n/a	n/a	n/a
Experiment 8									n/a	n/a	n/a
Lucerne cubes/grain control	1	892	187	n/a	n/a	411	70	0.94	n/a	n/a	n/a
41% Rape	1	217	203	n/a	n/a	202	25	2.60	n/a	n/a	n/a
Experiment 9									n/a	n/a	n/a
Pasture control	3	152	221	115	17	360	22	0.39	n/a	n/a	n/a
75:25 FB:pasture	3	172	122	489	10	163	16	3.38	n/a	n/a	n/a
Pasture control	3	150	191	130	15	406	16	0.37	n/a	n/a	n/a
90:10 FB:pasture	3	174	104	573	9	127	19	5.40	n/a	n/a	n/a

DM, dry matter; CP, crude protein; HWSC, hot water soluble carbohydrates; NDF, neutral detergent fibre; RFC:SC, readily fermentable carbohydrate to structural carbohydrate ratio; FB, fodder beet

[1]g/kg wet weight

[2]Ratio of RFC (HWSC + pectin): SC (NDF - lignin)

[3] mmol/kg, except for experiment 1 where units are g/kg for nitrate-N, sulphur and sulphate

Experiment 1: Sun et al. (2012)

Experiment 2: Sun et al. (2013a, 2015c)

Experiment 3: Sun et al. (2013b)

Experiment 4: Sun et al. (2014a)

Experiment 5: Sun et al. (2014b 2015a)

Experiment 7: Sun et al. (2015b)

Experiment 8:Williams et al. (2016)

Experiment 9: Pacheco et al. (unpublished)

4.2 Interpretation of Results

From the 9 experiments summarised in this report there were 331, 24 and 195 methane measurements from sheep and cattle fed either brassica forages, fodder beet and control diets (pasture or lucerne cubes/grain), respectively (Table 4.1). Figure 4.1 shows methane yield for each diet, as well as the percentage change in methane yield from the control diet (which is set as '0' or baseline). The diet with the greatest difference in methane yield was the 100% rape diet fed to sheep in Experiment 7 and the 90:10 fodder beet diet fed to sheep in Experiment 9, with respective reductions in methane yield compared to the control of -64% and -61%. Generally, all diets across the different experiments resulted in a reduction in methane yield compared to the control diet, with the exception of Experiment 4 where feeding bulb turnip to sheep increased methane yield by 13%, compared to ryegrass.

Figures 4.2 to 4.4 are regression plots of different variables, common across the majority of the experiments, against methane yield (Tables 4.2 and 4.3), for all brassica forages, fodder beet and control diets. Specifically, Figure 4.2 regresses DMD (g/kg), A:P ratio and rumen pH against methane yield. Note there was no fodder beet data available to include in these regressions. DMD ranged from 60 to 90% digestibility and as DMD increased, methane yield decreased (R^2 = 0.24). The diets of poorer DMD tended to be animals fed the pasture controls and at the other extreme, sheep fed a swede diet had a DMD of 89% (Experiment 1). The relationships of A:P ratio and rumen pH against methane yield, although poor (R^2 = 0.02 and 0.09, respectively), were both positive. Figure 4.3 regresses the main dietary chemical component concentrations (g/kg DM) of NDF, HWSC, CP and RFC:SC ratio, against methane yield (g/kg DMI). As NDF concentration increased, methane yield increased (R^2 = 0.40), whereas methane yield decreased when dietary concentrations of HWSC (R^2 = 0.16), CP (R^2 = 0.10) and RFC:SC ratio (R^2 = 0.34) increased (Figure 4.2).

To better understand the effect of RFC:SC ratio, it was regressed against A:P ratio and rumen pH. The different diets were individually identified so RFC:SC for each diet type could be regressed against methane yield (Figure 4.4). There was no A:P ratio or rumen pH data available for animals fed fodder beet. As RFC:SC ratio increased, A:P ratio (R^2 = 0.47), rumen pH (R^2 = 0.67) and methane yield (R^2 = 0.34 as given in Figure 4.3) all decreased. For the different diets, animals fed the pasture controls tended to have the highest methane yield and lowest RFC:SC ratio, whereas animals fed fodder beet had the lowest methane yield and highest RFC:SC ratio.

Brassicas forages contain plant secondary compounds including polyphenol oxidase, S-methyl L-cysteine sulphoxide (SMCO), glucosinolates, and can accumulate nitrate (Sun et al., 2012b). Experiment 1 undertook an extensive analysis of kale, rape, swedes, turnips and pasture diets and found SMCO, glucosinolates, nitrate, sulphur and sulphate could not explain reductions in enteric methane (Sun et al., 2012). The same was observed for Experiment 2 (Sun et al., 2015c) who reported that lower methane yields from lambs fed forage rape were not related to nitrate or sulphate in the feed.

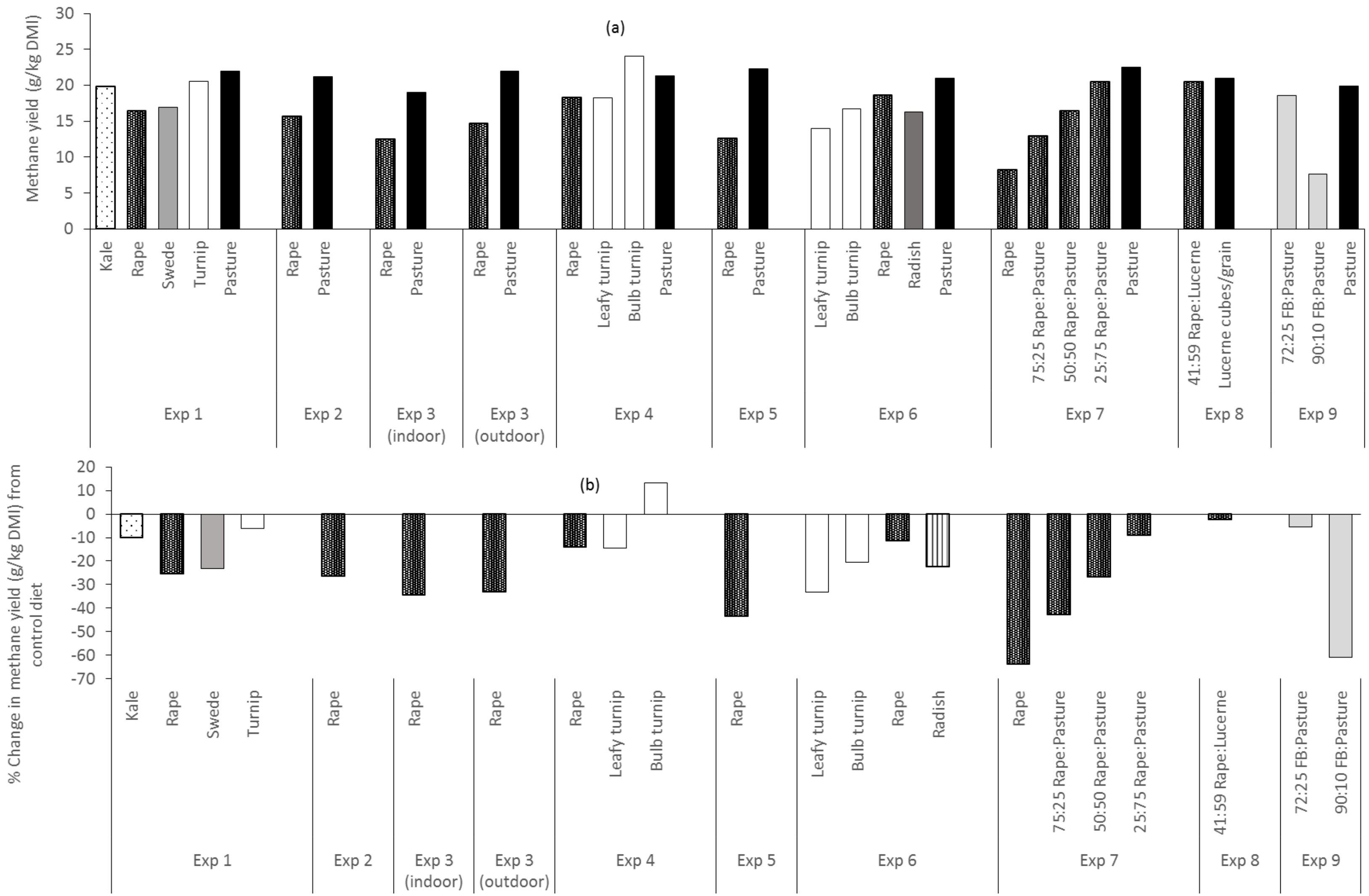

Figure 4.1 (a) Methane yield (g/kg DMI) and (b) the percentage change in methane yield from the control diet (set as '0' or the baseline), for each of the different dietary treatments fed within each experiment (Exp).

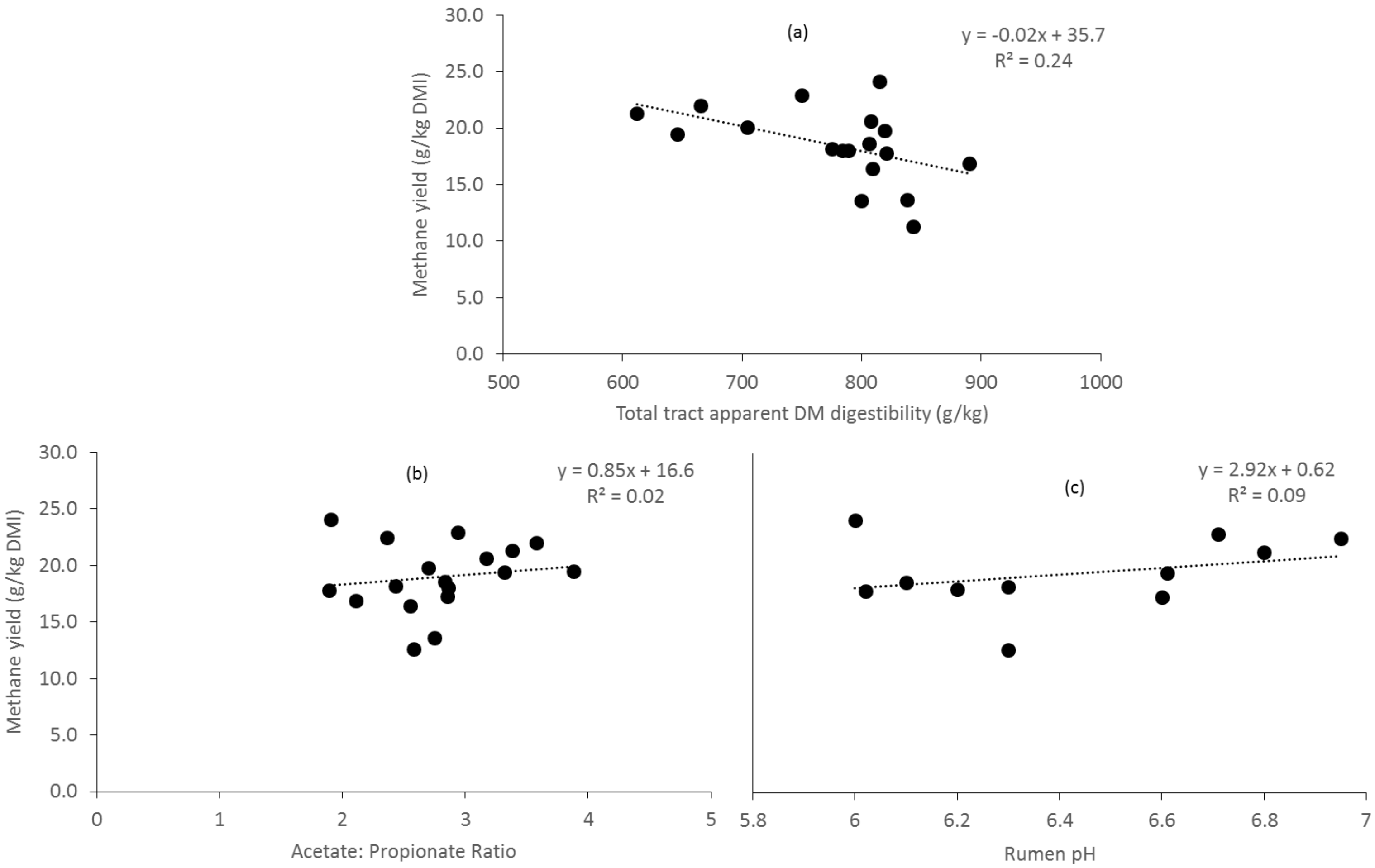

Figure 4.2 Summary of published data given in Tables 4.2 and 4.3, comparing (a) total tract apparent DM digestibility (DMD), (b) acetate:propionate ratio (A:P), and (c) rumen pH, against methane yield in sheep and cattle fed control diets (pasture or lucerne cubes/grain) and brassica forages (kale, rape, swede and turnip). NB no fodder beet data was available on DMD, A:P and rumen pH, or kale and swede data on rumen pH.

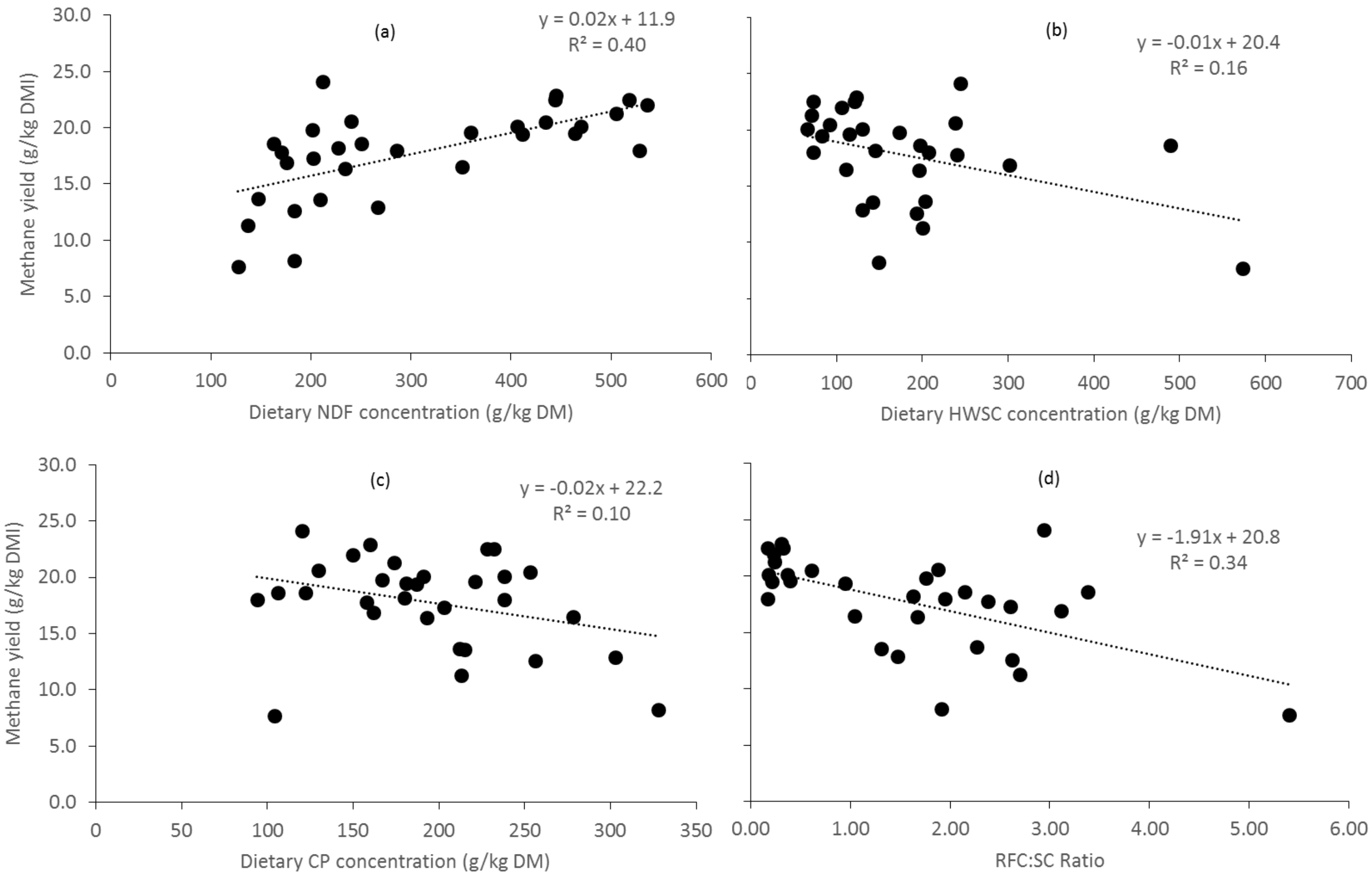

Figure 4.3 Summary of published data in Tables 4.2 and 4.3 comparing the relationship of individual dietary component concentrations (g/kg DM) of (a) neutral detergent fibre (NDF), (b) hot water soluble carbohydrate (HWSC), (c) crude protein (CP), and (d) readily fermentable to structural carbohydrate ratio (RFC:SC) against methane yield for sheep and cattle fed control diets (pasture or lucerne cubes/grain), brassica forages (kale, rape, swede and turnip) and fodder beet.

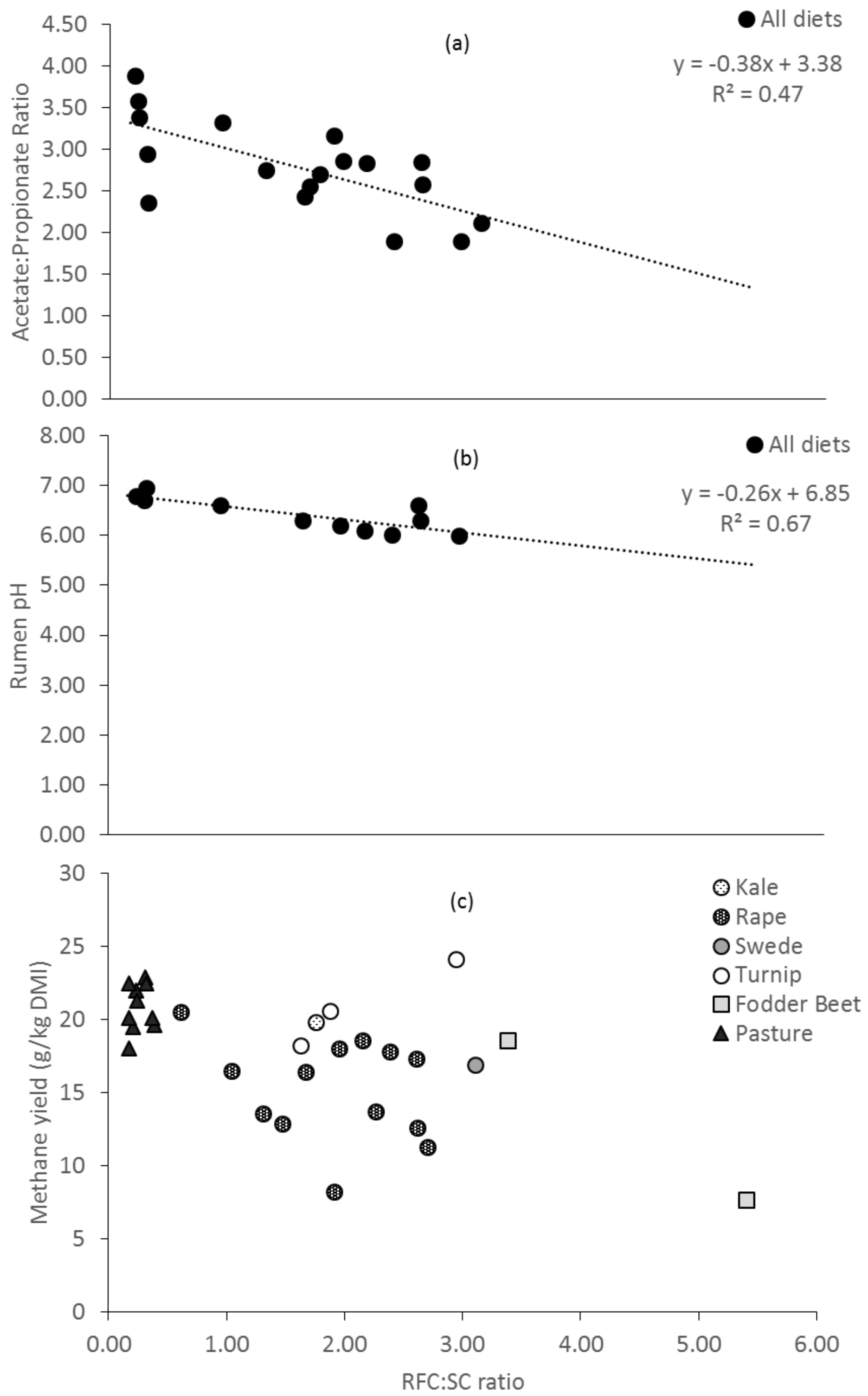

Figure 4.4 Summary of published data from Tables 4.2 and 4.3, comparing the relationship of (a) acetate to propionate ratio (A:P), (b) rumen pH, and (c) methane yield against readily fermentable to structural carbohydrate ratio (RFC:SC) in sheep and cattle fed control diets (pasture or lucerne cubes/grain), brassica forages (kale, rape, swede and turnip), and fodder beet. NB, there was no A:P or rumen pH data available for animals fed fodder beet, or rumen pH data for kale and swede diets.

4.3 Discussion

Feeding forage brassicas and fodder beet to sheep and cattle across several experiments tended to reduce methane yield by up to almost 64%. Of the brassicas, forage rape appeared to have the greatest mitigatory effect. Only one experiment on fodder beet was reported with a 61% reduction in methane yield for sheep fed a 90:10 fodder beet:pasture diet.

The proportion of brassica or fodder beet in the total diet did appear to have an influence on the extent of the reduction in methane yield. This was clearly shown in Experiment 7 where the proportion of forage rape increased from 25 to 100% of the total diet and methane yield decreased accordingly. No methane mitigation was observed for Experiment 8 which compared 41% forage rape to lucerne cubes/grain in lactating dairy cows. The authors of this experiment (Williams et al., 2016) concluded that the lower inclusion rate of rape may have been the possible reason for absence of an inhibitory effect on methane yield, however they emphasised that this inclusion rate was typical of diets fed to Australian dairy cows. A similar observation occurred with fodder beet; as the proportion of fodder beet in the diet increased, methane yield decreased (Experiment 9). However, caution should be exercised with the fodder beet results as data was available from only one experiment.

Of the eight experiments where brassica was fed (Table 4.2) only seven specifically compared brassica with pasture. Six of the experiments were with young (< 12 months old) sheep and one experiment used young cattle (9 months old). All of these studies have resulted in significant differences in terms of methane production (g/d) and methane yield (g/kg DMI). Across all seven experiments, compared to sheep and cattle fed conventional ryegrass pasture, animals fed brassicas, had 30.1% lower average methane yields. A recent review summarising many of the experiments listed here has been published by Sun et al. (2016). These authors also concluded that several species of brassica can result in varying reductions in methane yield from sheep, with similar mitigation responses observed with cattle. Winter forage rape resulted in 37% lower methane yields than pasture when fed to sheep. Animal age, the duration of feeding brassicas, feeding level, diet chemical composition and rumen fermentation patterns were all reported to be weakly correlated to methane emissions. Methane emissions were also found to be independent of whether forage rape was fed as primary growth or regrowth (18.0 versus 18.6 g/kg DMI, respectively; Experiment 4). Season was found to be a factor, with forage rape fed in winter resulting in lower methane yields than sheep feed in summer. Long term mitigatory effects of brassicas on methane emission were also investigated and it was found that forage rape reduced methane emissions by 30% at 7 weeks and 22% at 15 weeks (Experiment 2).

Based on the studies reported in this report and when compared to low quality ryegrass pastures, brassica forages and fodder beet generally had a high water content resulting in a low DM (range of 9-20%), low NDF (range of 13-29%), high HWSC (range of 14-30%) and pectin (range of 7-10%, with the exception of fodder beet where pectin concentration was low at 2%), and a highly variable CP concentration depending on plant species (fodder beet low at 11% and forage brassicas generally 11-19% except for rape which had concentrations as high as 33% in Experiment 7). As shown in the regressions in this report, the combination of low fibre and high sugar contents in the brassica and fodder beet forages led to reductions in enteric methane production but it unlikely that this is the sole reason for the reduction. It does support the generalisation that an increase in non-fibre sugar content leads to a more propionate-based fermentation pattern which in turn decreases the amount of hydrogen produced (Janssen, 2010) and consequently leads to lower methane emissions (Muetzel and Clark, 2015). The strong negative correlation of methane yield with CP content was also interesting but no plausible explanation can be given for this effect. Despite these overall correlations, for the majority of the individual experiments reported here that the reduction in methane yield did not correlate with the chemical composition of the diets. It may be that the diet composition has indirect effects on other variables that are better able to explain reductions in enteric methane. For example, Sun et al. (2016) speculated that the high concentrations of lignin and NDF, together with higher DM content of the summer versus winter crop may have resulted in lower rumen passage rates and consequently increased methane emissions, as passage rate is reported to be associated with methane yield (Hammond et al., 2014). A faster passage rate would explain lower methane production as methanogens get washed out of the rumen, leading to an increase in dissolved hydrogen and hence acting as a feedback mechanism resulting in less hydrogen and therefore less methane (Janssen, 2010). However, this does not appear to be the case with the brassica data where ruminal liquid passage rate measured from sheep fed forage rape was slower than those fed pasture (0.103 versus 0.193/h, respectively; Experiment 2; Sun et al. 2015c) despite the DM content in the forage rape less than that in ryegrass (142 versus 198 g/kg fresh weight, respectively; Experiment 2). This suggests other factors are contributing to a reduction in enteric methane.

It is further postulated that differences in the ratio of RFC:SC may have an influence. Sun et al. (2015c) in Experiment 2 demonstrated that the greater amount of soluble carbohydrate elicited changes in the fermentation pattern which favoured the establishments of bacterial communities known to produce less hydrogen during fermentation. Based on Figure 4.3, it would appear that a higher RFC:SC ratio drives a lower methane yield, however the majority of the variation was unaccounted by RFC:SC ratio. High amounts of sugars are needed to reduce methane production in ruminants and the effect may not be driven only by changed sugar fermentation pathways but by a decrease in pH (Muetzel and Clark, 2015). Rumen pH tended to be lower in animals fed forage brassicas than pasture, indicating that rumen pH may have a role to play in methane reduction. Methanogens are sensitive to low pH (Hook et al., 2010) but in order to decrease pH below 5.5, large amounts of soluble sugars are needed. It would seem possible that the concentrations of sugar found in brassica forages and fodder beet is sufficient to reduce methane production by influencing reductions in rumen pH and affecting microbial communities which leads to less methane being formed in the rumen.

There were large variations in the few experiments that measured nitrate, sulphur, sulphate, glucosinolates and SMCO concentrations. Although toxic at high concentrations, nitrate can reduce methane production in the rumen as nitrate and sulphate are effective alternative hydrogen sinks (Nolan et al., 2010, van Zijderveld et al., 2010). The concentration of nitrate was reported to be greater in the winter versus summer forage rape crops which may partly account for the lower methane yields from winter crops. However, this was more closely examined in Experiment 2 (Sun et al., 2015c) who concluded that differences in methane emission were not driven by nitrate and sulphate in the feed. Furthermore, both Experiments 1 and 2 found total glucosinolates and SMCO were not linked with methane yield reductions.

4.4 Summary

Forage rape has been the most intensively studied brassica in terms of enteric methane mitigation. Limited studies have shown less of an effect on enteric methane with other brassica forages e.g. turnip, but further research needs to verify these limited data. The experiments reported here typically involve small numbers of animals and there is significant between-animal variation as well as (presumably) errors in measurement. Thus, it is difficult to detect differences in methane output between relatively similar feed types. There is only one experiment reported here on the effect of fodder beet but these results suggest the reductions on enteric methane are even greater than for forage rape. Research is needed to identify the mechanism as to why some brassica forages and fodder beet are able to have such a marked influence on enteric methane. Limited experimental results indicate that nitrate, sulphate and SMCO play only a minor role in methane mitigation, however, the relationship of RFC:SC ratio and indirect effects on passage rate, rumen pH and hydrogen sinks show promise. Before brassica and fodder beet forages are included in the New Zealand GHG Inventory other variables that can influence GHG emissions, such as soil cultivation, grazing management and environmental processes of nitrate leaching, nitrification, N_2O emissions and soil carbon accumulation also need to be considered.

5 NITROUS OXIDE EMISSION

5.1 Summary of Experiments

There were a total of nine experiments investigating N_2O emissions from brassica forages (rape or kale) or fodder beet. These experiments were all conducted in New Zealand, through both the North and South Islands and covering a variety of soil types (Table 5.1). The focus on the source of N_2O emission varied with experiments. Experiments 1, 2, 3, 4 and 5 were the only experiments to compare N_2O emissions from forage brassica with a ryegrass pasture control. Experiments 1, 2, 3, 4 and 9 focused on the application of urine N from animals fed brassica, pasture or fodder beet diets, applied to either brassica, pasture or fodder beet soils and measured N_2O emissions. Experiment 1 was the only experiment to apply both urine N and faecal N, sourced from animals fed either brassica or pasture diets, on soil N_2O emissions. Experiment 5 investigated N_2O emissions based on the application of fertiliser N to brassica crops and also assessed the impact of animal grazing. Experiment 6 focused on the impacts of soil compaction with brassica crops on N_2O emissions, and experiments 6, 7, and 8 investigated DCD for mitigation of brassica urine N_2O emissions.

The main approach in these experiments for measuring N_2O emissions from field soils was the soil chamber technique described by de Klein et al. (2002). Generally, gas sampling was continued until background or control N_2O levels were reached, with the majority of emissions occurring during the first 3 or 6 months after application of urine. The N_2O emissions factor (EF3) was calculated from the difference in total emissions from each treatment, divided by the rate of urine-N or dung-N applied. The EF3 from urine and faeces are the most important factors to consider in terms of reducing N_2O emissions and this data has been the focus of the experiments presented in Table 5.2. The exception is Experiment 5, which was focused on the effects of urea applied N and used EF1 for urea application where EF1 = % of applied fertiliser – N lost as N_2O.

Table 5.1 Experimental location and soil type for investigating nitrous oxide emissions from brassica forages, ryegrass and fodder beet

Experiment	Location	Forage investigated	Soil type
Experiment 1	Ruakura Farm, Hamilton	Forage Rape & Ryegrass	Poorly drained silt-loam Te Kowhai soil
Experiment 2	Aorangi Research Farm, Palmerston North	Forage Rape & Ryegrass	Poorly drained silt-loam Kairanga soil
Experiment 3	Aorangi Research Farm, Palmerston North	Forage Rape & Ryegrass	Poorly drained silt-loam Kairanga soil
Experiment 4	Aorangi Research Farm, Palmerston North	Forage Rape & Ryegrass	Poorly drained silt-loam Kairanga soil
Experiment 5	Ruakura, Hamilton	Forage Rape & Ryegrass	Free-draining volcanic Horotiu silt loam soil
Experiment 6	South Otago	Kale	Poorly drained Te Houka silt loam soil
Experiment 7	Woodlands Research Station, Southland	Kale	Pukemutu silt loam soil
Experiment 8	Woodlands Research Station, Southland	Kale	Pukemutu silt loam soil
Experiment 9	Lincoln University Ashley Dean Farm, Christchurch	Kale & Fodder Beet	Balmoral stony silt loam soil

Experiment 1 Sun et al (2013a), Luo et al (2013a, 2015a)
Experiment 2 Sun et al (2013b)
Experiment 3 Sun et al (2014a, 2015a)
Experiment 4 Sun et al (2014b, 2015a)
Experiment 5 Luo et al (2015b)
Experiment 6 Van der Weerden & Styles (2012)
Experiment 7 Monaghan et al (2013)
Experiment 8 Smith et al (2008)
Experiment 9 Di et al (unpublished)

Table 5.2 Nitrous oxide emissions from soils growing either brassica or ryegrass with the application of urine or faeces from animals fed either brassica or ryegrass forages.

Soil Type	Season	N source		Treatment/conditions	Volume applied	N application rate	Total N_2O emission	Emission factor (EF3)
		Type	Species		L/m² (urine) or kg/m² (faeces)	kg N/ha	g N/ha	%
Experiment 1								
Rape	Winter	Rape urine	Sheep	Brassica	4	155	170	0.11
Ryegrass	Winter	Ryegrass urine	Sheep	Ryegrass	4	441	1190	0.27
Rape	Winter	Rape faeces	Sheep	Brassica	5	890	710	0.08
Ryegrass	Winter	Ryegrass faeces	Sheep	Ryegrass	5	430	130	0.03
Experiment 2								
Rape	Winter	Rape urine	Sheep	Brassica	4	152	n/a	3.53
Rape	Winter	Ryegrass urine	Sheep	Brassica	4	304	n/a	2.03
Rape	Winter	Control, no N	n/a	Brassica		0	1005	n/a
Ryegrass	Winter	Rape urine	Sheep	Ryegrass	4	152	n/a	1.72
Ryegrass	Winter	Ryegrass urine	Sheep	Ryegrass	4	304	n/a	1.49
Ryegrass	Winter	No N	n/a	Control		0	570	n/a
Experiment 3								
Rape	Summer	Rape urine	Sheep	Brassica	4	108	n/a	0.10
Ryegrass	Summer	Ryegrass urine	Sheep	Ryegrass	4	280	n/a	0.08
Rape	Summer	Ryegrass urine	Sheep	Brassica	4	280	n/a	0.07
Ryegrass	Summer	Rape urine	Sheep	Ryegrass	4	108	n/a	0.18
Rape	Summer	No N	n/a	Control		0	388	n/a
Ryegrass	Summer	No N	n/a	Control		0	92	n/a
Experiment 4								
Rape	Winter	Rape urine	Cattle	Brassica	10	300	n/a	1.98
Ryegrass	Winter	Ryegrass urine	Cattle	Ryegrass	10	410	n/a	2.02
Rape	Winter	Ryegrass urine	Cattle	Brassica	10	410	n/a	1.51
Ryegrass	Winter	Rape urine	Cattle	Ryegrass	10	300	n/a	2.18
Rape	Winter	No N	n/a	Control		0	1339	n/a

Ryegrass	Winter	No N	n/a	Control		0	147	n/a
Experiment 5								
Rape	Winter	No N		Control		0	450	n/a
Rape	Winter	Fert		Brassica + fert		80	1450	1.28[1]
Ryegrass	Winter	No N		Control		0	140	n/a
Ryegrass	Winter	Fert		Ryegrass + fert		80	210	0.09[1]
Rape	Winter	No N		Brassica		0	1440	n/a
Rape	Winter	Urine/faeces	Cattle	Brassica + grazed		n/a	4140	n/a
Ryegrass	Winter	No N		Ryegrass		0	110	n/a
Ryegrass	Winter	Urine/faeces	Cattle	Ryegrass + grazed		n/a	430	n/a
Rape	Winter	Fert, urine/faeces	Cattle	Brassica + fert + grazed		80	5590	n/a
Ryegrass	Winter	Fert, urine/faeces	Cattle	Ryegrass + fert + grazed		80	640	n/a
Experiment 6								
Swede	Winter	No N	Cattle	Non compacted soil		n/a	4040	n/a
Swede	Winter	No N	Cattle	Compacted soil		n/a	2490	n/a
Swede	Winter	No N	Cattle	Compacted soil + DCD		n/a	2420	n/a
Swede	Winter	Urine	Cattle	Compacted soil + urine	10	190	8230	3.00
Swede	Winter	Urine	Cattle	Compacted soil + urine + DCD	10	190	4080	0.90
Swede	Winter	No N	Cattle	Non compacted soil		n/a	2160	n/a
Swede	Winter	No N	Cattle	Compacted soil		n/a	2530	n/a
Swede	Winter	Urine	Cattle	Compacted soil + urine	10	190	8940	3.30
Experiment 7								
Kale	Winter	?		Control		n/a	2200	n/a
Kale	Winter	?	Artificial	Control + urine patch	2 (L/0.3 m^2)	399	7700	1.41
Kale	Winter	?		Control + whole plot		399	3600	n/a
Kale	Winter	?		DCD		n/a	2000	n/a
Kale	Winter	?	Artificial	DCD + urine patch	2 (L/0.3 m^2)	399	4500	0.65
Kale	Winter	?		DCD + whole plot		399	2700	n/a
Kale	Winter	?		Control		n/a	700	n/a
Kale	Winter	?	Artificial	Control + urine patch	2 (L/0.3 m2)	528	3900	0.65
Kale	Winter	?		Control + whole plot		528	1500	n/a
Kale	Winter	?		DCD		n/a	800	n/a

Kale	Winter	?	Artificial	DCD + urine patch	2 (L/0.3 m^2)	528	2900	0.40
Kale	Winter	?		DCD + whole plot		528	1300	n/a
Experiment 8								
Kale	Winter	?		Control		n/a	2200	n/a
Kale	Winter	?	Artificial	Control + urine patch	2 (L/0.3 m^2)	387	7700	1.41
Kale	Winter	?		Control + whole plot		n/a	3600	n/a
Kale	Winter	?		DCD		n/a	2000	n/a
Kale	Winter	?	Artificial	DCD + urine patch	2 (L/0.3 m^2)	387	4500	0.65
Kale	Winter	?		DCD + whole plot		n/a	2700	n/a
Experiment 9								
Fodder beet	Winter	Fodder beet urine	Cattle	Fodder beet		300	n/a	3.8
Fodder beet	Winter	No N		Control	2 (L/0.5 m^2)	0	n/a	1.3
Kale	Winter	Kale urine	Cattle	Kale		300	n/a	6.1
Kale	Winter	No N		Control		0	n/a	3.0

Experiment 1 Sun et al (2013a), Luo et al (2013a, 2015a)
Experiment 2 Sun et al (2013b)
Experiment 3 Sun et al (2014a, 2015a)
Experiment 4 Sun et al (2014b, 2015a)
Experiment 5 Luo et al (2015b)
Experiment 6 Van der Weerden & Styles (2012)
Experiment 7 Monaghan et al (2013a)
Experiment 8 Smith et al (2008)
Experiment 9 Di et al (unpublished)
DCD, dicyandiamide; EF3 = N_2O-N total (urine) – N_2O-N total (Control)/urine – N applied
[1]EF1 emission factor for urea application where EF1 = % of applied fertiliser – N lost as N_2O

5.2 Interpretation of Results

Table 5.2 summarises the reported EF3 values for each of the 9 experiments. Experiment 1 used samples of urine and faeces from sheep fed forage rape or pasture diets and applied it to soils to measure N_2O emissions. The EF3 for urine from sheep fed rape (0.11%) was lower by about 60% than urine from sheep fed ryegrass (0.27%). In contrast, the EF3 for faeces from sheep fed forage rape (0.08%) was 2.68 x higher than faeces from sheep fed ryegrass (0.03%), but this difference was not significant. The EF3 from faeces was lower than that from urine. Experiment 2 was a field study to measure N_2O emissions from urine patches applied to soil growing both forage rape and pasture swards. EF3 was highest for forage rape urine applied to forage rape soils (3.53%) and lowest for ryegrass urine applied to ryegrass soil (1.49%), however this difference was not significant due to the large variation in EF3 across the different treatments. For Experiment 3, urine from lambs fed forage rape or ryegrass was applied to soils growing either forage rape or ryegrass swards. EF3 for urine-rape was more than double pasture urine but the difference was not significant (0.14 and 0.07%). Experiment 4 measured N_2O emissions in winter from soils to which urine of cattle which had been fed either forage rape or pasture had been applied to either soil growing forage rape or pasture. The EF3 from cattle urine patches was not different between urine or forage types, with mean EF3 values of 1.77 and 2.08% for the pasture and forage rape, respectively. Experiment 5 investigated the effects on EF1 of urea application on forage rape crops compared to permanent pasture. EF1 for fertiliser urea was 1.28% when 80 kg N was applied to a forage rape crop, yet when the same amount of urea was applied to permanent pasture, the EF1 values for applied fertiliser was 0.09%. Experiment 6 found that DCD application significantly reduced EF3 on a swede crop by 71% (3.3 to 0.9%) and that overall there was no significant difference in compacted vs non-compacted soil on EF3 because of large variability in the data. Experiment 7 found that although the application of DCD on kale crops was associated with a substantial DCD-induced reduction of urine EF3, differences were not significant. Experiment 8 investigated DCD for the reduction of EF3 on kale crops and reported a significant reduction of 54% (1.41% untreated vs. 0.65% for DCD-treated). Experiment 9 measured EF3 from urine of cows fed either fodder beet or kale and applied to fodder beet or kale crops. EF3 from cow urine on fodder beet were 39% lower than from kale with the same urine N application.

5.3 Discussion

With agricultural intensification, high inputs of N fertilisers and protein-rich feeds have contributed to high livestock production levels, but as much as 70-95% of ingested N is not retained in animal products (i.e. milk and meat) but excreted in urine and faeces. The N in urine and faeces results in N losses to the environment in the form of ammonia (NH_3), nitrous oxide (N_2O), nitric oxide (NO), di-nitrogen (N_2) and nitrate (NO_{3-}) (Dijkstra et al. 2011). Nitrous oxide (N_2O) emissions from grazed pastures have been a research focus due to its importance as a GHG. Animal excreta deposited during grazing is the largest single source of N_2O and responsible for over 80% of the direct and indirect N_2O emissions from New Zealand agriculture (de Klein and Ledgard, 2005). There has been a 23% increase in New Zealand's agricultural emissions since 1990, primarily due to an 88% increase in dairy cow numbers and 5-fold increase in fertiliser nitrogen (N) use (Ministry for the Environment, 2015). The majority of N is returned as urine, in forms more readily transformed to N_2O than N in faeces. As N intake increases, the proportion of N excreted in the faeces remains relatively constant, while the portion excreted in the urine increases. The N loading rate in urine patches often exceeds the N requirements of pasture and the excess is then lost. This makes the urine patch a conduit through which much of N is recycled in grazed pasture systems.

Experiments 1, 2, 3 and 4 compared EF3 from urine sourced from animals fed both brassica and ryegrass diets. Experiments 2, 3 and 4 reported a higher EF3 with urine from animals fed brassicas compared to ryegrass, however the differences were not significant due to the high variability of the data. Inability to demonstrate significant differences between urine types, despite a 2-fold difference in many instances, is a reflection of high within-treatment variability in EF3.

Experiment 1 was the only experiment where EF3 was lowest for urine from forage rape fed sheep compared to urine from ryegrass fed sheep. Although this may have been driven by differences in N loading rate (as a constant urine volume was applied) which was lower for urine from forage rape than urine from ryegrass (155 vs 441 kg N/ha, respectively), this higher N loading rate (kg N/ha) for the brassica forages, compared to ryegrass, was common across all experiments (Experiment 2, 152 vs 304; Experiment 3, 108 vs 280; and Experiment 4, 300 vs 410). There is some evidence that N in forage rape urine undergoes a faster transformation from organic N to ammonium N then to nitrate N than ryegrass urine when applied to soil. Some authors have postulated that plant secondary metabolites may be transferred in the urine and affect soil N transformation processes. This is based on the concept of glucosinolates, a major group of secondary compounds in brassicas whose degradation products have been found to act as a nitrification inhibitor when directly added to soil (Bending and Lincoln, 2000; Snyder et al., 2010). Mechanisms of urine N transformation rates are needed for different urine compositions as it may offer a prospect as a future N_2O mitigation strategy.

There was significant variability in the EF3 values reported and this was largely related to higher EF3 values in winter compared to summer. The higher EF3 values reported in Experiment 2 are postulated to be due to the low plant density of the crops as well as low soil temperatures and short day lengths resulting in low plant uptake of N. In contrast, Experiment 1 applied urine N in spring, had a higher soil temperature, longer day lengths, and dense, actively growing plant swards for greater plant uptake of N. With lower plant uptake of urine N more is available for nitrification and denitrification leading to higher N_2O emissions.

Use of DCD as mitigation tool for reducing N_2O emissions from brassica forages in general appeared to reduce EF3, but the data are variable so differences were not always statistically significant. It would be interesting to know the effects of DCD across a variety of well replicated brassica forages, fodder beet and ryegrasses in the same experiment.

Emissions from fodder beet were 39% lower than from kale. Reasons for this large difference are unclear but as with the DCD experiments, a direct comparison with pasture would be useful. Authors hypothesise that differences between fodder beet and kale may be due to differences in the urine constituents from the different forages. For example, some constituents such as isothiocyanates can affect N cycling in the soil and lead to lower N_2O emissions (Bending and Lincoln, 2000). Further research is needed to characterise urine composition to assess potential effects on N cycling once urine is applied to the soil.

5.4 Summary

The EF3 reported across experiments was hugely variable and largely inconclusive. Apart from Experiment 1, forage brassicas tended to have a higher EF3 than pasture, however the variability in the data meant that large differences were not significant. Variables such as season, type of urine used (and faeces in some cases) and N concentration (i.e. interactions between urine/faeces from brassica/pasture-fed animals with soils growing brassica/pasture herbage), N loading rate in the urine patch and application volume, animal species (cattle vs. sheep), treatments of added N or DCD, are some of many influences which make it very difficult to determine whether EF3 are affected by the diet the animal has been grazing. Many of the measurements were undertaken over a short duration (i.e. 3 months) and under different soil and climatic conditions, so it is uncertain how reproducible values are. It is likely that the different ways brassicas are used commercially will affect the EF3 values – e.g. cold wet conditions under strip grazing vs hot dry under a more lax grazing system. A better understanding of this is needed and a determination as to whether the EF3 factors need to be different or whether they average out.

It is important to note that the planting and growth of brassica and fodder beet crops may affect N_2O emissions, as the amount of N_2O emitted is affected by many soil factors such as mineral N content, soil aeration, soil water and availability of degradable organic matter (Choudhary et al., 2001). These factors are all affected by soil cultivation for planting and have not been considered in great detail here. Life cycle analyses need to account for these factors so to better understand the overall impact brassica forages and fodder beet have on whole system GHG emissions.

6 LIFE CYCLE ANALYSIS

Brassicas are commonly used in New Zealand for many reasons. These include providing a source of feed during periods of feed shortage in the summer, autumn and winter; to supplement periods of low pasture quality; to finish stock; as a summer-safe feed; and often prior to pasture renewal. There is some discrepancy as to the area of brassica grown in New Zealand. For example, Sun et al. (2014) refers to an area of 500,000 ha of brassica grown annually (PGG Wrightson per comm). Yet New Zealand Agricultural Statistics indicate areas of 222,877 ha in 2009 and 246,528 in 2012. Even if the PGG Wrightson estimate is correct it is of little use unless it can be substantiated from a source such as New Zealand Agricultural Statistics. Moreover, there have been significant plantings of fodder beet as a feed for wintering dairy cows in recent years which suggests that brassica use is likely to have plateaued rather than continue to increase.

Assuming the area grown in brassicas across New Zealand is 250,000 ha, and average yields are 10,000 kg DM/ha, this would result in 2.5 million tonnes of brassica grown annually. Assuming 80% utilisation (Valentine and Kemp, 2007), the total amount of brassica consumed annually by farmed ruminants in New Zealand is approximately 2 million tonnes of DM. This comprises 3.9% of the estimated 51.8 million tonnes of DM consumed by NZ farmed ruminants (Wear, 2013). Assuming each kg of DMI results in 21.4 g of methane, 2 million tonnes of DM consumed will produce 42,800 tonnes of methane. Assuming a 30% reduction in methane output, the feeding of brassicas should reduce the output of methane by farmed ruminants of 12,840 tonnes (or 321,000 tonnes of CO_2-equivalents). Brassicas have a wide range of forms (bulb, stem and leafy top) and offer flexibility in terms of forage type and seasonal availability. Brassicas tend to be high yielding and enable large amounts feed to be transferred to periods of deficit. Yields of winter kale crops can be as high as 21.3 tonnes DM/ha (de Ruiter et al. 2009), and yields of up to 15.5 tonnes DM/ha have been reported for bulb turnips as a winter feed (Collie and Mackenzie, 1998). On the other hand, forage rape crops grown for summer feed yield considerably less DM (e.g. 6.9 tonnes DM/ha; de Ruiter et al. 2009) as they have less time to accumulate DM before grazing. It is likely that there are many cases of poor yielding crops that go unreported and that nationally, an average brassica yield of 10 tonnes per ha seems reasonable.

Brassica crops are typically 85-90% digestible with an energy concentration of 12-13 MJ ME/kg DM and a crude protein content of 15-25% in leaves and 8-15% in the bulbs (Valentine and Kemp, 2007). Although forages of this quality would normally be expected to deliver high animal performance, a review by Barry (2013) suggested average body growth rates of young sheep ranged from 95 g/day fed swedes, 120 g/day fed kale, 173 g/day fed turnips and 225 g/day fed forage rape. These are not dissimilar to the range of growth rates for similar aged lambs on pasture and seem to reflect differing concentrations of SMCO and glucosinolates, both of which have the potential to depress voluntary feed intake (Barry 2013). Moreover, many brassica crops are grown to provide bulk feed for winter maintenance (e.g. swedes for winter feeding ewes) rather than as a high performance crop for finishing stock. It is hard to see how on a national basis, brassicas are contributing to increases in animal performance on a per kg DM basis.

There is limited data available for a lifecycle analysis on the use of brassicas. A brassica crop requires the ground to be prepared ready for planting – this can involve a full cultivation or a spray and a direct drill – both of which have different costs. Brassicas need additional fertiliser inputs over and above what tends to be used on established pastures. Then there may be additional costs in terms of the way the crops are fed out, for example the need for daily moves vs situations where a larger area is being grazed. These costs tend to be over and above that of a permanent pasture and will vary for cultivars and the various management systems as do the plant yields. Ledgard and Falconer (2015) calculated that turnip bulbs and kale would have respective carbon footprints of 0.264 and 0.192 kg CO_2-equivalent/kg DM. They felt the main source of additional GHG emissions (N_2O) came from the application of additional nitrogen fertilisers (36%), the manufacture of DAP and urea (20%) along with CO_2 field emissions from lime (10%) – these fertiliser costs amount to 0.174 to 0.127 kg CO_2-equivalent/kg DM. If we assume a national crop of 2.5 million tonnes of brassica, this will result in between 317,000 and 435,000 extra tonnes (mean 376,000 tonnes) of CO_2-equivalent generated from the additional fertiliser requirements. While these values are outside the calculation for the agricultural emissions they will contribute to New Zealand's overall emissions. In addition, Ledgard and Falconer (2015) found 15% of the additional emissions came from pasture and crop residues and less than 7% from the diesel used for farm operations. Because fertiliser emissions are accounted for elsewhere, the national agricultural footprint from growing 2.5 million tonnes of brassica will result in 125,400 tonne of CO_2-equivalent over and above that of the equivalent pasture. As indicated previously, a 30% reduction in methane output from the feeding of brassicas should reduce the output of methane by farmed ruminants of 12,840 tonnes (or 321,000 tonnes of CO_2-equivalents). This suggests that there will be a net benefit of 195,600 tonnes of CO_2-equivalents from feeding forage brassicas. This assumes all brassica reduce methane in a similar way to forage rape.

However, the above calculations do not consider any effect on animal-associated N_2O emissions as currently there is no evidence for any consistent effect of brassicas on N_2O production. More work is needed to clarify both the animal and EF3 effects. These include the EF3 that are relevant to the different farming systems e.g. from a break feeding type system in the middle of winter to summer feeding in places like the Hawkes Bay where the ground is drier and the temperature is higher and the animals tend to be moved less frequently.

The limited data available means the calculation is heavily weighted towards forage rape which tends to have better reductions than the other brassicas which have been examined. New Zealand Agriculture Statistics numbers do not separate out the various types of brassicas grown, when they are grown or what class of stock they are fed to. Better data on the areas and yields of the different brassicas will be required to enable a better estimate to be made.

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