Tradeoffs and Interactions between Pasture and Concentrate on Milk Fatty Acid Profile

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(Editor's Note: This paper is being summarized from the PowerPoint presentation given at the 2017 Conference. Some of the narrative is my interpretation of the findings in the various slides presented at the Conference. This paper is a review of the literature on pasture feeding effects on fatty acid content of cow's milk. I deemed it too important to not include it in the Proceedings as it reinforces much of what is said elsewhere in the Proceedings. Its format, however, will deviate from the other submitted papers.)

This paper covers two major subjects:

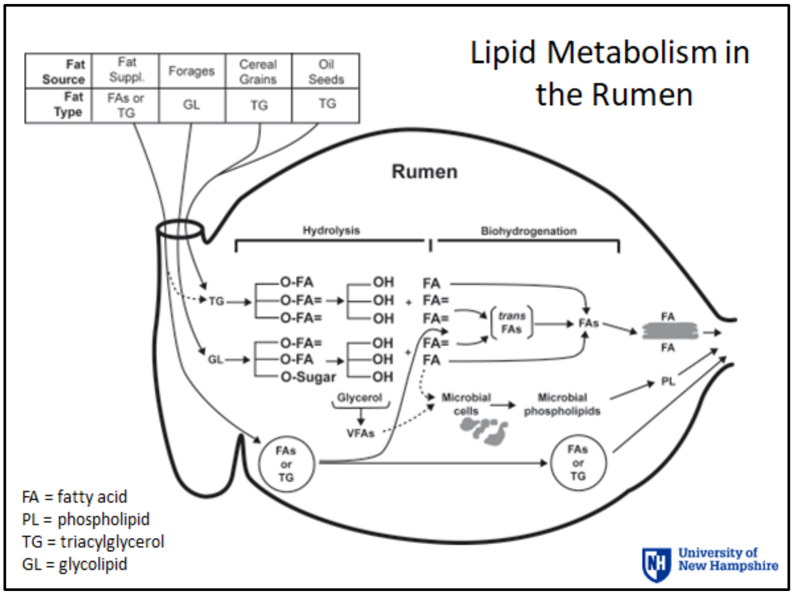
- Lipids metabolism in the rumen, and
- Pasture allowance, supplementation, botanical composition, and tradeoffs between milk fatty acids and milk yield.

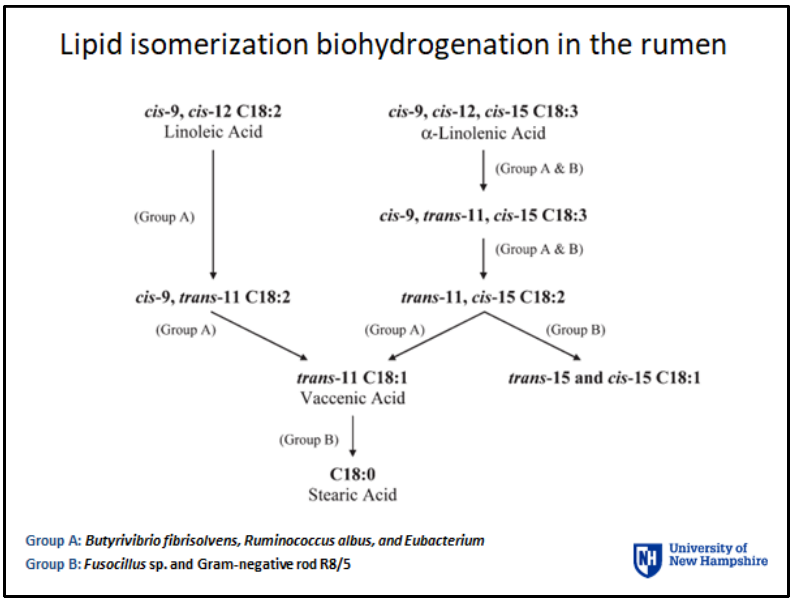
In preparing this review paper, the Dr. Brito used the following methodology. The Agricola database (1970-2017) was used to search for research papers. Key words used were "grazing and milk fatty acids in dairy cows". Approximately 180 hits occurred that yielded 20 papers with at least 1 treatment as a pasture-only diet and they used pasture allowance, cereal grain concentrate, and pasture botanical composition as determining factors among others in how a pasture diet affected fatty acid composition in cow's milk and milk yield.

Fatty acids profile of cow's milk is affected by:

1. Fresh forage and concentrate eaten (Croissant et al., 2007; Coppa et al., 2013)
2. Differences within and between breed (Soyeurt et al., 2008; Maurice-Van Eijndhoven et al., 2011)
3. Season (Heck et al., 2009)
4. Climate (Kamleh et al., 2010)
5. Stage of lactation (Craninx et al., 2008)
6. Management (Fall et al., 2008)

The rumen transforms lipids (fats) that come from forages and roughages, concentrates (grains and oil seeds), and fat supplements. Forages/roughages fats are glycolipids. Grains and oil seed fats are triacylglycerols. Fat supplements are either fatty acids (FA) or triacylglycerols or a mix of the two depending on the source. Phospholipids are introduced into the rumen by diet or by microbes in the rumen. Below there is a figure that



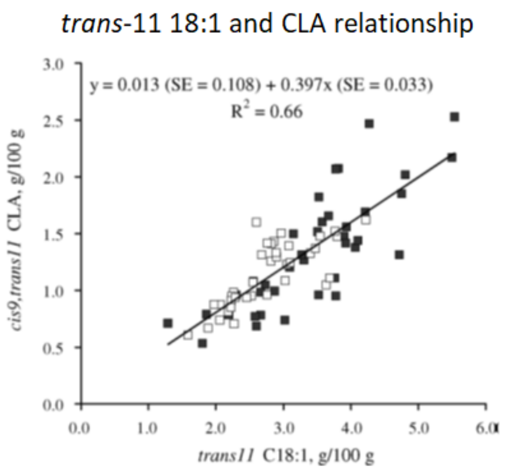


shows how the ingested FA are converted into other FA by the rumen bacteria. Two major processes occur in the rumen to transform ingested FA to FA useful to the animal and produce milk fat: hydrolysis and biohydrogenation. There are also some fats that do not undergo any transformation and go directly to the lower gastrointestinal tract (See bottom of the rumen diagram).

The next figure is a schematic of biohydrogenation of lipids in the rumen. Two groups of rumen bacteria, Group A & Group B, are at work. Depending on the FA ingested, linoleic acid or linolenic acid, these two groups convert them into a different FA, vaccenic acid(Group A), that is in turn converted into C18:0 stearic acid, a saturated fat (Group B), or trans-15 and cis-15 C18:1 Octadecenoic acids (Group B). These last two isomers are not further hydrogenated. α-linolenic acid (ALA) is the major unsaturated FA ingested by the animal grazing on pasture. It is present primarily in glycolipids, but also to a lesser extent in phospholipids. Group A and B are both needed to hydrogenate it. Group A makes it into vaccenic acid, while Group B forms the two Octadecenoic acids. If the animal is given supplements, a significant amount of linoleic acid (LA) enters the rumen, primarily as a triacylglycerol (TG). Group A rumen bacteria hydrogenate it (Harfoot, 2012).

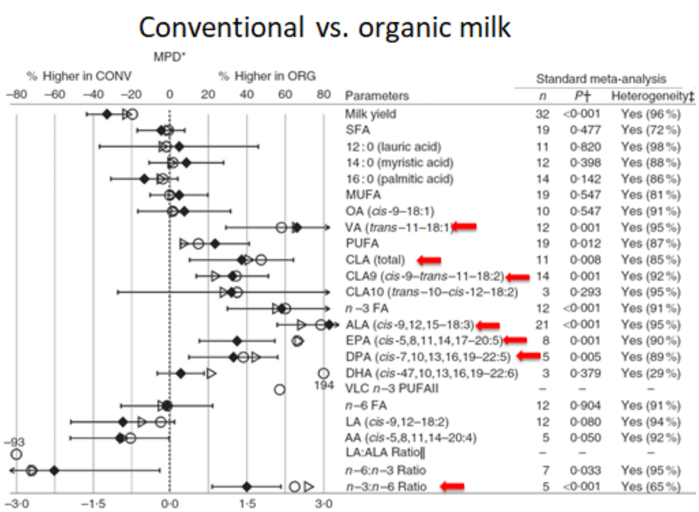
Some of the vaccenic acid is also converted into CLA as shown in the figure below. The CLA in milk fat results from ruminal microbial biohydrogenation of dietary C18:2 (linoleic acid) and desaturation by mammary gland Δ^9-desaturase of trans11 C18:1 (vaccenic acid), with more than 75% of total CLA in milk fat originating by internal synthesis in the cow. CLA isomers have been reported to have a wide range of beneficial effects, such as anti-carcinogenic, antiatherogenic, anti-diabetic, and anti-obesity (Bargo et al., 2006).

Since milk fat is the richest natural source of CLA, it is worthwhile to try to improve levels of CLA in milk with dietary changes to the milk cow's feed ration. However, with one proviso, we do not strip it out at the milk plant to produce low or no-fat dairy products. As seen in the adjacent figure, the more vaccenic acid that there is in cow's milk, the more CLA pre-sent, in linear fashion. Dairy cows tend to produce more CLA on pasture than they do fed a to-tal mixed ration in confinement, or if fed supplements on pas-ture. Although C18:3, the pre-dominant FA in pasture forages, does not form CLA in the rumen, it can form trans-11 C18:1 that can be de-saturated in the mam-mary gland by Δ9-desaturase to form CLA (Bargo, 2006).



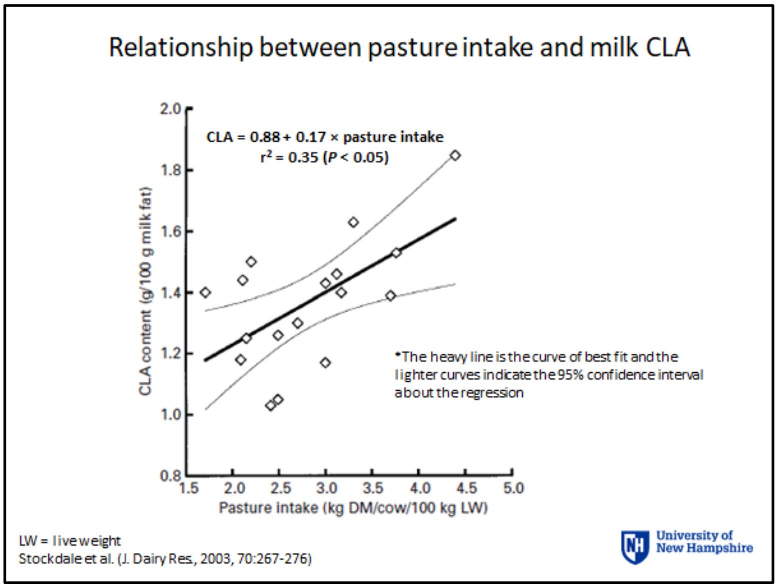
Relationship between milk content of cis9, trans11 CLA and trans11 C18:1 in unsupplemented (U; (■)) and supplemented (CS; (□)) dairy cows grazing at two pasture allowances.
Bargo et al. (Anim. Feed Sci. Technol., 2006, 125:17–31)

The next figure compares conventionally-produced milk versus organic milk. Conven-tional production is defined as cows in confinement and fed a feed ration high in con-centrates. Organic production requires lactating animals to be on pasture (fresh forage is a majority of the feed ration) as conditions permit. It must be stated that the distinguish-ing feature of all this is: the lactating animals are fed primarily or wholly fresh forage in season. Higher fat levels may be lost when cows are off-pasture unless the fed ration can mimic what occurs on pasture.

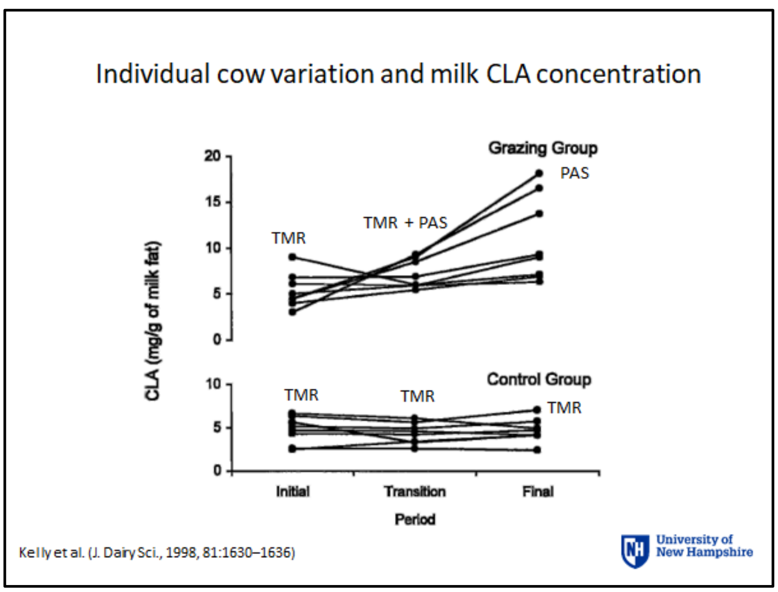


OA, oleic acid; VA, vaccenic acid; CLA, conjugated linoleic acid; ALA, α-linolenic acid; VLC n-3 PUFA, very long-chain omega-3 PUFA (EPA+DPA+DHA); LA, linoleic acid; AA, arachidonic acid
*MPD = mean percentage difference
Średnicka-Tober et al. (British J. Nutr., 2016, 115:1043–1060)

The red arrows in the ad-jacent figure are pointing out where organic milk had sig-nificantly higher levels than did conventional milk. Note the extremely low P values at those FA with red arrows, P= <0.05. Total CLA and CLA9 (dominant CLA isomer found in milk), omega-3 (n-3), ALA, EPA, DPA, and the omega-3: omega-6 (n-3:n-6) without a doubt are much higher in organic milk judging by the miniscule P values. Vaccenic acid (VA) is metabolized into CLA9 by mammals, including humans; thus, its importance in being more plentiful in organic milk. No significant differences in the con-centration of total n-6 polyunsaturated fatty acids (PUFA) and LA (the dominant n-6 FA found in milk) were found between organic and conventional milk. However, there were significantly lower concentrations of the n-6 PUFA AA (another n-6 FA) in organic milk. This made the omega-6:omega-3 ratio much higher in conventional milk than in organic milk, or the inverse ratio omega-3:omega-6 much higher in organic milk than in conventional (Średnicka-Tober, 2016). The n-6:n-3 ratio in the average American diet is believed to be much too high; whereas pastured cow's milk is consistently well below the level set at 4.0 as the limit for best health, unless fresh forage intake is lowered excessively with supplemental feed.



The adjacent figure shows that, indeed, the higher the intake of vegetative pasture forage is, the higher the content of CLA in the cow's milk. The R^2 value is low as there is a lot of scatter in the data plotted on the graph; several of which are outside the 95% confidence level. However, there is a definite upward trend in CLA content with more pasture forage being consumed. If supplements are fed, this can decrease the amount of grass ingested by 0.6 pound for each pound of supplement fed **if** a high pasture allowance is used (Bargo, 2002).



In the adjacent figure, it is seen that on pasture there are definite differences among Holstein cows on their ability to respond to fresh pasture forage and increase their milk's content of CLA. Total mixed rations (TMR) tended to washout any difference in response by individual cows to increased CLA in their milk. Three cows in the grazing group had increased CLA concentrations in their milk; the other five did not when they only consumed pasture forages. This would explain partially why the R^2 in the Stockdale et al. study was so low (explained only a third of observed variability). Dairy cow genetics play a role in the response to grazing fresh grass with increased CLA content in milk. Stanton (1997) reported that the variation in milk fat CLA levels among individual cows over two trials was 0.15–1.6 g/100 g of milk fat. If increased CLA content of milk is desirable and there is an incentive to increase it, culling cows with no or little response to a grass-only pasture ration might be explored. Stocking some cows on pasture may do little to increase CLA in their milk.

Pasture allowance and dry corn-based concentrate

	Treatments[1]			P <[2]	
	Low PA	High PA	SEM	PA	Period
Pasture management					
Pasture allowance, kg DM/cow/d	26.7	48.9	1.4	<0.01	0.43
Area, m^2/cow/d	102	179	5	<0.01	<0.01
Pregrazing herbage mass, kg DM/ha	2712	2809	99	0.49	<0.01
Postgrazing herbage mass, kg DM/ha	1013	1575	43	<0.01	0.01
Efficiency of harvesting, %	62	42	2	<0.01	0.02
Chemical composition					
% of DM	21.7	21.4	0.5	0.69	<0.01
% DM					
OM, %	92.0	92.2	0.1	0.28	<0.01
CP, %	20.3	19.6	0.4	0.29	<0.01
Soluble CP, %	4.8	4.7	0.3	0.81	<0.01
NSC, %	14.2	15.3	0.3	0.03	<0.01
NDF, %	56.1	55.2	0.5	0.26	<0.01
ADF, %	28.3	27.3	0.3	0.04	<0.01
In vitro DM digestibility, %	70.3	73.0	0.7	0.01	0.01

[1]Low PA = Low pasture allowance (25 kg DM/cow/d); High PA = high pasture allowance (40 kg DM/cow/d).

[2]PA = Effect of pasture allowance, Period = effect of period.

Bargo et al. (J. Dairy Sci., 2002, 85:1777–1792)

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Pasture allowance is important so that lactating cows do not have to scrounge for forage intake; when they do, milk production decreases. The targeted PA for the low and high PA treatments were 25 and 40 kg DM/cow per day, respectively. Actual PA for the low and high PA treatments averaged 27 and 49 kg DM/cow per day, respectively (P < 0.01). The larger amount of pasture offered was provided by adjusting the paddock size (102 vs. 179 m^2/cow/day [circled red], for low and high PA, respectively), because the pregrazing pasture mass between pasture treatments did not differ and averaged 2761 kg of DM/ha (P > 0.05). Cows grazing at a low PA had lower average post grazing pasture mass (1013 vs 1575 kg DM/ha; P < 0.01). The efficiency of harvesting, defined as pasture consumed/pasture offered, was significantly greater at low PA (62 vs. 42%; P < 0.01) (Bargo, 2002). One might consider following the lactating cows with another herd type to cleanup unused available forage.

Although not shown in the above table of averages, pasture quality varied among periods. This is why the P values are so low for effects of period for all entries in the table except for pasture allowance. Without a doubt the growth period made a big difference in the chemical composition of the pasture forage, P = <0.01. Comparing the spring periods (periods 1 and 2) and the fall periods (periods 3 and 4), the authors reported in their narrative that pasture had higher DM (26.9 vs. 16.1%), NDF (59.4 vs. 51.9%), and ADF (28.7 vs. 26.8%), and lower NSC (13.9 vs. 15.5%) and IVDMD (70.7 vs. 72.6%) during the spring because spring pasture was grazed at a more advanced stage of maturity due to the rapid pasture growth getting ahead of the grazing rotation. These nutrient composition values are typical for the type of spring pastures found in the northeast US (Bargo, 2002).

Effect of pasture allowance was significant for NSC, ADF, and in vitro dry matter digestibility (IVDMD). This is due to the cows having a high enough pasture allowance that they could high grade their intake to get a better nutritional plane on at least these three forage quality indicators. NSC and IVDMD values were higher and ADF lower making the ingested forage more nutritional at the high allowance than the low allowance. This resulted in better milk production as seen in the next figure for Bargo et al.

Pasture allowance and tradeoffs between milk CLA and milk yield

References	CLA, g/100 g			Milk yield, kg/d		
	Low PA	High PA	*P*	Low PA	High PA	*P*
Bargo et al. (2002, 2006)[1]	1.23	1.30	NS	24.4	26.1	0.04
Wales et al. (1999)[2]	1.40	1.40	NS	23.3	28.4	<0.05
Stockdale (2000; trial 1)[3]	1.20	1.50	<0.05	28.7	31.2	<0.05
Stockdale (2000; trial 2)[4]	1.00	1.10	NS	24.3	26.7	<0.05
Stanton et al. (1997)[5]	0.39	0.59	<0.05	-	-	-

[1]27 vs. 49 kg DM/cow/day (16.5 vs. 18.3 kg pasture DMI); smooth bromegrass, orchardgrass, Kentucky bluegrass
[2]20 vs 70 kg DM/cow/day (8.5 vs. 17.9 kg pasture DMI); perennial ryegrass, white clover
[3]25 vs. 50 kg DM/cow/day (14.1 vs. 19.3 kg pasture DMI); perennial ryegrass, white clover
[4]25 vs. 50 kg DM/cow/day (11.3 vs. 13.4 kg pasture DMI); perennial ryegrass, white clover
[5]16 vs. 20 kg DM/cow/day; perennial ryegrass

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As seen in the adjacent figure increasing CLA in milk is not readily achieved by upping the PA for cows. Three out of the 5 studies saw no significant change in milk CLA content by increasing the PA. However, going to a higher PA did increase milk yield significantly in the 4 studies that reported milk yield. The Stanton study is an outlier from the other 4 studies in its low CLA levels. Its PA levels are both low as its higher allocation only reaches the lowest low PA (Wales) of the other 4 studies. The cows in the Stanton study varied widely in their production of CLA in their milk. This could have skewed the CLA g/100 g of milk fat downward depending on where all the cows fell between the highest (1.6 g/100 g) and the lowest (0.15 g/100 g). It would appear most of them produced little CLA as they produced only 32-44 percent of the CLA the other 4 studies averaged, although the low PA did not help. At its high PA of 20 kg DM /cow/day, the CLA content was beginning to catch up to the observed results of the other 4 studies, 44% of the other 4 studies versus 32% at the low PA of 16 kg DM /cow/day. This would indicate that a higher PA most likely would have produced more CLA. A study by Lawless et al. (1999) compared 4 breeds' production of CLA and found little variation among them, but found wide variations in milk fat CLA between individual cows within the four breeds ranging from 0.48 to 3.56 g/100g milk fat. The four breeds were Irish Holstein/Friesians, Dutch Holstein/Friesians, Montbeliardes, and Normandes.

Replacing pasture with a barley/wheat-based concentrate

Item	Concentrate levels						SED	*P*
	0	3	5	7	9	11		
Pasture DMI, kg/d	12.1[d]	12.0[d]	11.2[c]	10.6[bc]	10.4[b]	9.2[a]	0.33	<0.01
Concentrate DMI, kg/d	0.0	3.0	5.0	7.0	9.0	11.0	-	-
Milk yield, kg/d	12.4[a]	15.6[b]	18.3[c]	19.9[cd]	20.7[d]	21.9[d]	1.06	<0.01
Milk fat, %	4.48[b]	4.21[b]	4.09[b]	4.05[b]	4.18[b]	3.25[a]	0.18	<0.01

[a, b, c, d] Means with different superscript differ significantly
Stockdale et al. (J. Dairy Res., 2003, 70:267-276)

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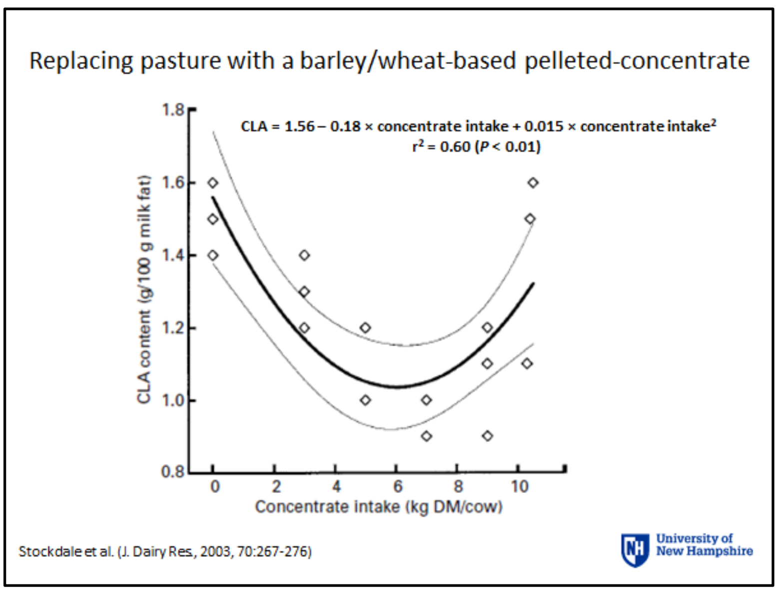
The nearby figure shows what happens to pasture intake, milk yield, and percent milk fat when pasture is replaced with more and more grain concentrate. Pasture intake per cow fell from 12.1 kg/d to 9.2 kg/d when concentrate level fed went from 0 to 11 kg/day/cow. Milk production, though, rose from 12.4 kg/d to 21.9 kg/day/cow. However, at 11 kg/day/cow concentrate level percent milk fat plummets to 3.25% after holding relatively steady up to 9 kg/day/cow of concentrate after a statistically insignificant drop at the lowest level of concentrate fed, 3 kg/day/cow. In this experiment, it would ap-pear that PA was low comparing actual DMI values shown in the previous figure at for the low PA targets set by the first four research trials with the 12.1 kg DM/d consumed when on grass-only here. Increased milk production was directly related to total DMI (combines pasture and concentrate). The cows went from consuming 12.1 kg DM/d on grass-only to 20.2 kg DM/d at the highest concentrate level when pasture con-sumption was only 9.2 kg DM/d. A higher PA could have produced more milk on grass-only. With the big drop in milk fat at 11 kg/d concentrate intake, were the cows undergoing milk fat depression? The concentrate made up more than half of their DMI. As reported by Walker et al. in 2001, they opined that this reduction in milk fat content was probably due to the effects of sub-clinical rumen lactic acidosis. Their hypothesis was supported by a trend to lower rumen pH for longer periods as supplement intake increased along with a more variable milk yield at the highest level of supplement intake (Walker, et al, 2001).



Feeding fresh pasture alone (grass-only) resulted in high concentrations (1.0-1.8 g/100 g milk fat) of CLA. When the effect of level of pasture consumption on CLA content was examined, a significant positive relation-ship ($r^2 = 0.35$; $P < 0.05$) was obtained. When grain concen-trates were used to supplement pasture intake, the CLA content of milk fat generally declined ($P < 0.05$), except where the level of concentrate (11 kg DM/d) giv-en led to a marked reduction in total milk fat concentration to 3.25% from ≈ 4.1% at all lower grain concentrate levels (Stockdale, 2003). Otherwise, CLA declines as more concentrate or other supplements are fed. On a pasture-based farm, the situation where more concentrate DM is fed than pasture DM intake is a scenario to avoid for herd health and profitability. It would have been far better to have stopped at 9 kg DM/d of concentrate fed in this particular example (See Replacing pasture with a barley/wheat-based concentrate figure on previous page).

Pasture supplementation and tradeoffs between milk CLA and milk yield

	CLA, g/100 g			Milk yield, kg/d		
References	NO	YES	*P*	NO	YES	*P*
Bargo et al. (2002, 2006)[1]	1.36	1.18	0.01	21.8	29.8	<0.01
Dhiman et al. (1999)[2]	2.21	1.16	0.001	14.5	21.0	0.01
Walker et al. (2001)[3]	1.50	1.07	<0.01	12.4	19.6	<0.01
Stockdale (2000; Trial 1)[4]	1.50	1.20	<0.01	29.0	30.9	<0.05
Stockdale (2000; Trial 2)[5]	1.20	0.90	<0.01	25.0	26.1	<0.05
Dalley et al. (2001)[6]	1.60	2.30	NS	25.6	28.1	NS
Wales et al. (2009)[7]	1.50	1.30@6 kg/d	NS	26.0	28.3	NS

[1]Dry corn-based concentrate (8.6 kg/d)
[2]Supplement: alfalfa hay, ground high-moisture corn, roasted soybean, soybean meal (6.0 and 1.6 kg/d)
[3]Barley/wheat-based pelleted-concentrate (3, 5, and 7 kg/d)
[4]Barley/wheat-based pelleted-concentrate (4.7 kg/d)
[5]Barley/wheat-based pelleted-concentrate (4.1 kg/d)
[6]Barley/wheat-based pelleted-concentrate (5.4 kg/d)
[7]Barley steam-flake corn-based concentrate (3 and 6 kg/d)

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The adjacent figure is a summary of the different experiments reviewed that looked at CLA content in grams per 100 grams of milk fat. The first two listed research works were done in the US; the rest of the work was done in Australia. The top five show that with increasing supplementation, CLA decreases. With Dalley et al., there actually was an increase in CLA with supplementation. This occurred on spring pastures that were 64 percent perennial ryegrass and 21 percent other grasses. Only 5.4 kg/d of barley-wheat pellets were fed which is much less DM than was pasture forage intake (11.2-18.7 kg/cow-day) that went up as forage allowance, (20-70 kg DM/cow-day) increased. The Wales et al. research not only looked at two relatively low supplementation levels of 3 and 6 kg/d of barley and steam-flaked corn concentrate on perennial ryegrass pasture; they also compared NZ and North American (NA) strains of Holstein-Friesians. Differences in milk yield and g. CLA per 100 g. of milk fat based on level of concentrate fed were not significant statistically. However, the NA strain cows produced significantly more g. CLA per 100 g. of milk fat (P = < 0.05) and milk yield (P = 0.08) than their NZ counterparts. This perhaps explains why the two research studies done in the US (Bargo and Dhiman) were helped by their cows genetics as well as the dietary changes in significantly increased production of CLA and milk. Wales et al. concluded that NA cows fed grass-only resulted in a milk FA composition that would likely be most beneficial from a human health perspective; however, this would need to be balanced against other productivity aspects between NZ and NA cows.

Strom used six different pasture mixtures that were categorized as either a simple or a diverse pasture. The three simple mixtures all included white clover (cv. Kopu II) and were sown with either a standard diploid perennial ryegrass (RG cv. One50), a diploid high sugar ryegrass (HS cv. Abermagic) or with tall fescue (TF cv. Advance). The three diverse mixtures included each of the simple mixtures with the addition of either chicory, plantain, prairie grass and red clover (RGD), chicory, plantain and big trefoil (HSD), or chicory, plantain, prairie grass and alfalfa (TFD). In all six combinations the base grasses were infected with either AR1 or MaxP endophyte. AR1 is an 'animal safe' ryegrass endophyte that produces only the compound peramine, however the endophyte does not protect the plant from insect attack as well as the wild-type endophyte. MaxP (AR542) is an ‘animal safe’ tall fescue endophyte that produces loline alkaloids instead of ergovaline that causes fescue toxicosis.

Simple vs. diverse pasture mixtures

	HS	*HSD*	*RG*	*RGD*
High sugar ryegrass	75.35	22.63		
Standard ryegrass			77.29	30.86
Tall fescue				
White clover	1.91	0.85	2.20	3.90
Chicory		56.69		32.93
Plantain		3.91		5.31
Alfalfa				
Red clover				20.35
Prairie grass				2.04
Dead plant material	22.60	13.92	20.44	4.49

Ström (2012)
HS - diploid high sugar p. ryegrass; HSD - HS + chicory, plantain and big trefoil
RG - standard diploid p. ryegrass; RGD - RG + chicory, plantain, prairie grass and red clover

The adjacent figure displays only the simple and diverse perennial ryegrass mixtures' composition. The simple ryegrass mixtures were dominated by perennial ryegrass, the white clover component was almost nonexistent. The diverse mixtures have a relatively low ryegrass component. The high sugar ryegrass diverse mixture was 57 percent chicory and 4 percent plantain, a high forb content. The standard diploid ryegrass diverse mixture was 33 percent chicory, 5 percent plantain and 20 percent red clover for a total of 62 percent forb content when including white clover. It is interesting to note that there is much less standing dead plant material in the diverse mixture swards. The high sugar content of the ryegrass seems not to have any effect on animal preference or utilization over the standard ryegrass. Fully 20 percent of the forage in the grazing zone is left to die and lower forage quality at next grazing.

Simple vs. diverse pasture mixture

Item	HS[1]	HSD[2]	*P*-value
Milk yield, kg/d	16.9	15.4	NS
Milk fat, %	3.32	3.41	NS
c-9, *c*-12 18:2, g/100 g FA	0.61	0.89	<0.001
ALA, g/100 g FA	0.61	0.91	<0.001
t-11 18:1, g/100 g FA	3.24	3.12	NS
c-9, *t*-11 CLA, g/100 g FA	1.62	1.52	NS

[1]HS = high-sugar perennial ryegrass simple pasture mixture
[2]HSD = high sugar perennial ryegrass diverse pasture mixture
Ström (2012)

Although milk yield went down some (not statistically significant), LA (n-6) and ALA (n-3) (highlighted by red box) were both significantly higher in the milk of the cows grazing the diverse high sugar ryegrass pasture mixture. The same holds for LA and ALA content in the milk of cows grazing the standard perennial ryegrass diverse pasture mixture. Note that the LA:ALA (omega-6:omega-3) ratio is 1. Pastured cows fed no supplements.

Simple vs. diverse pasture mixture

Item	RG[1]	RGD[2]	*P*-value
Milk yield, kg/d	15.8	16.9	NS
Milk fat, %	3.42	3.48	NS
c-9, *c*-12 18:2, g/100 g FA	0.65	0.97	<0.001
ALA, g/100 g FA	0.65	0.99	<0.001
t-11 18:1, g/100 g FA	3.20	3.00	NS
c-9, *t*-11 CLA, g/100 g FA	1.68	1.38	NS

[1]RG = standard perennial ryegrass simple pasture mixture
[2]RGD = standard perennial ryegrass diverse pasture mixture
Ström (2012)

Cows on the high sugar ryegrass pasture (HS) had a higher daily milk production compared to cows on the standard ryegrass pasture (RG). These results are similar to other studies where diets consisting of high sugar ryegrasses increased milk production. Although different studies have not shown unanimity, ryegrasses with higher sugar content have been shown to increase milk production by improving ruminal amino acid utilization for microbial protein synthesis as a result of a better supply of easily available carbohydrates, such as water soluble carbohydrates (WSC). Although the WSC content did not differ between the pastures, the HS pasture had a higher organic matter digestibility (OMD) than the RG and higher protein content (16.21 vs. 13.41%). Yet, when including more plant species in the pasture, the RGD treatment resulted in higher milk yield compared to the HSD treatment and the same as the HS treatment. This may be due to the lower amount of high sugar ryegrass in the pasture as it was supplanted by more plant species along with the fact that the RGD pasture had higher crude protein content (16.24 vs. 13.67%) and a much higher proportion of red clover (24.20 vs. 0.85% of DM). The lower production in cows grazing HSD and RG pastures may also be due to the low white clover content in those pastures (Strom).

Abundance of plant species in DIV and PROD plots ranked in descending order (for species whose abundance is greater than 0.005).

	DIV			PROD	
	Mean	s.e.m		Mean	s.e.m
Agrostis capillaris	0.185	0.0133	*Dactylis glomerata*	0.225	0.0235
Trifolium repens	0.136	0.0199	*Taraxacum gr. officinale*	0.201	0.0258
Festuca rubra ssp. rubra	0.097	0.0087	*Trifolium repens*	0.198	0.0280
Plantago lanceolata	0.053	0.0089	*Elymus repens*	0.066	0.0183
Achillea millefolium	0.051	0.0084	*Lolium perenne*	0.064	0.0218
Veronica chamaedrys	0.038	0.0065	*Holcus mollis*	0.052	0.0114
Carex caryophyllea	0.033	0.0058	*Agrostis capillaris*	0.045	0.0153
Helianthemum nummularium	0.029	0.0093	*Poa pratensis*	0.044	0.0113
Poa pratensis	0.025	0.0064	*Poa annua ou supina - vivace*	0.019	0.0056
Galium verum	0.023	0.0039	*Poa trivialis*	0.017	0.0080
Dactylis glomerata	0.023	0.0092	*Plantago major*	0.014	0.0054
Thymus pulegioides s.l.	0.022	0.0054	*Festuca rubra ssp. rubra*	0.007	0.0077
Holcus mollis	0.016	0.0047	*Plantago lanceolata*	0.007	0.0046
Hieracium pilosella	0.015	0.0051	*Festuca arundineacea*	0.006	0.0053
Festuca nigrescens ssp. nigrescens	0.014	0.0042	*Rumex obtusifolius*	0.005	0.0019
Meum athamanticum	0.014	0.0045	*Bromus hordeaceus ssp. hordeaceus*	0.005	0.0016
Chamaespartium sagittale	0.013	0.0045	–	–	–
Viola lutea	0.012	0.0030	–	–	–
Anthoxanthum odoratum	0.011	0.0034	–	–	–
Trifolium pratense	0.010	0.0022	–	–	–
Avenula pubescens	0.009	0.0029	–	–	–
Ranunculus acris	0.009	0.0023	–	–	–
Stachys officinalis	0.008	0.0045	–	–	–
Gentiana lutea	0.008	0.0034	–	–	–
Trisetum flavescens	0.008	0.0022	–	–	–
Briza media	0.008	0.0035	–	–	–
Cynosurus cristatus	0.007	0.0029	–	–	–
Rhinanthus minor	0.007	0.0037	–	–	–
Ajuga reptans	0.007	0.0027	–	–	–
Potentilla tabernaemontani	0.006	0.0019	–	–	–
Scabiosa columbaria	0.006	0.0021	–	–	–
Lathyrus pratensis	0.006	0.0026	–	–	–
Festuca lemanii	0.006	0.0031	–	–	–
Euphrasia rostkoviana	0.006	0.0027	–	–	–
Stellaria graminea	0.006	0.0023	–	–	–
Poa chaixii	0.005	0.0052	–	–	–
Cytisus scoparius	0.005	0.0028	–	–	–

s.e.m: Standard error of the mean.

Farruggiaet al. (Agriculture, Ecosystems and Environment, 2014 185:231–244)

University of New Hampshire

Two contrasting grazing systems were evaluated by Farruggia et al. from May to September for two years. The treatments were: a continuous grazing system (DIV) managed at a relaxed stocking rate (1.0 LU ha^{-1}) [LU = 500 kg body weight] on a very diverse specie permanent pasture and a rotational grazing system (PROD) done at a higher stocking rate (1.7 LU ha^{-1}) on a former temporary grassland having moderate biodiversity. DIV sought to maximize biodiversity and obtain high sensory and nutritional quality cheese, whereas PROD was oriented towards milk production and herbage quality. In each system, 12 unsupplemented Montbéliarde cows were used. DIV cows showed a higher degree of loss of body condition than the PROD cows over the season.

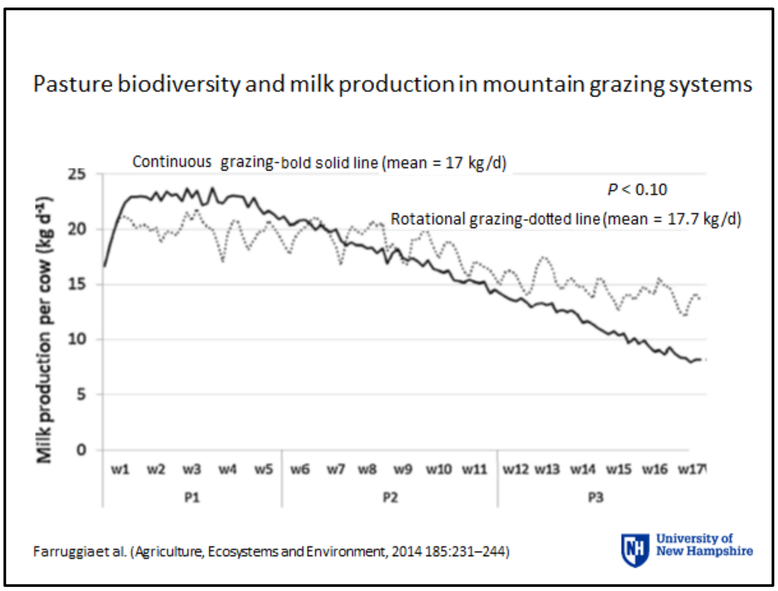
Pasture biodiversity and milk fatty acids in mountain grazing systems

FA, g/100 g	ContG-H[1]	RotG-L[2]	SEM	*P*-value
c-9 18:1	20.5	19.8	0.33	<0.10
c-9, *c*-12 18:2	1.19	0.83	0.05	<0.001
ALA	0.94	0.73	0.03	<0.001
t-11 18:1	3.80	4.33	0.26	<0.01
c-9, *t*-11 CLA	1.64	2.22	0.12	<0.001

[1]ContG-H = continuous grazing with higher botanical diversity
[2]RotG-L= rotational grazing with lower botanical diversity
Farruggia et al. (Agriculture, Ecosystems and Environment, 2014 185:231–244)

University of New Hampshire

In terms of milk fatty acid profile, the DIV system proved most interesting early in the grazing season but lost its value over time as the herbage matured (Farruggia et al.). The relaxed stocking of the continuously grazed pasture (DIV) most likely was the reason for the loss of forage quality as the pasture season progressed. The cows had more forage than they could eat early-on during the spring flush of growth and spot grazing would have developed. This creates a pattern of closely grazed areas of vegetative forage and areas of mature, uneaten grasses and forbs. As forage availability decreases, the overgrown areas will be eventually, but begrudgingly, grazed. Its forage quality will be subpar. Therefore, it is not so much the fault of the plant community but the grazing management employed. LA (c-9, c-12 18:2) and ALA were significantly higher in the milk produced by the DIV system than by the PROD system, but vaccenic acid (t-11 18:1) and CLA were significantly higher in the PROD system than in the DIV system. Again, we see a very low omega-6 (LA) to omega-3 (ALA) ratio in the milk, 1.27 for DIV and 1.14 for PROD.



The continuous grazing system (DIV) led to higher milk production per cow early in the grazing season than the rotational grazing system (22.2 vs. 19.9 kg/d). At the beginning of summer (week 7), this milk production pattern changed following a decrease in grass nutritive value in the DIV system and the milk production by the PROD cows became greater (Farruggia et al.). The cow herd that was rotational stocked had the highest seasonal milk production 17.7 kg/d versus 17.0 kg/d for cows that were stocked continuously on the diverse pasture. Forage quality is maintained better when pasture is rotationally grazed if allocated forage at each grazing requires them to eat all or nearly all the available forage. This works against milk production early in the season because their forage intake will be restricted so that milk flow is dampened somewhat, as it was in this experiment repeatedly as witnessed by the choppy lactation curve. The herd was rotated when mean daily milk production fell below a threshold corresponding to 88% of the maximum milk production obtained on the paddock. Sward height at pre-grazing was only 8.4 cm too in the second year. The continuously grazed pasture cattle had unrestrained intake early in the lactation cycle, but later-on forage quality decreased (over mature and standing dead) that dampened intake and consequently milk flow. Dead material was lower in PROD herbage mass (HM) than in DIV HM (−10 percentage points, $p < 0.01$), and it increased markedly in DIV HM over the 3 periods (+79 and +72% respectively (Farruggia et al.). The lactation curve for the continuous grazing is on a steeper decline from week 4 to week 17 than is the lactation curve for the rotational pasture cows. At week 17, daily milk production per cow on rotational pasture is ≈ 5 kg more than for the cows on continuously grazed pasture.

Botanical composition of the plots used for the three pastures of low, moderate, and high biodiversity

Item	No. of species	Proportion of ground cover (%)		
		Total	Species >10 %	Species 1–10 %
Experiment 1: temporary grassland	17			
Grasses	5	76.2	*Dactylis glomerata, Lolium perenne*	*Elymus repens, Poa annua*
Legumes	1	7.1		*Trifolium repens*
Other species	11	16.7		*Taraxacum officinale, Capsella bursa-pastoris, Plantago major*
Experiment 1 moderately biodiversified pasture	31			
Grasses	13	73.6	*Dactylis glomerata, Alopecurus pratensis*	*Poa pratensis, Festuca rubra, Phleum pratense, Bromus mollis, Agrostis tenuis, Arrhenaterum elatius, Trisetum flavescens*
Legumes	3	7.1		*Trifolium repens, Lathyrus pratensis*
Other species	15	19.3		*Stellaria graminea, Achillea millefolium, Cerastium glomeratum, Stellaria media, Veronica chamaedrys, Cerastium funtanum, Alchemilla vulgaris*
Experiment 1 highly biodiversified pasture	50			
Grasses	14	52.3	*Festuca rubra, Agrostis capillaris*	*Festuca ovina, Briza media, Phleum phleoides, Trisetum flavescens, Poa pratense, Avenula pubescens*
Legumes	5	1.5		*Trifolium repens*
Other species	31	46.2		*Thymus pulegioides, Plantago lanceolata, Achillea millefolium, Veronica chamaedrys, Galium verum, Gentiana lutea, Rumex acetosella, Cerastium fontanum, Stellaria graminea, Viola lutea, Luzula campestris, Cerastium tomentosum, Conopodium majus*

Note: Number of species count is based on presence. Right-most column includes only species that are between 1 and 10% ground cover.

Coppa et al. (Anim. Feed Sci. Technol., 2015 208:66–78)

University of New Hampshire

Coppa et al. as a portion of their research work (experiment 1) looked at how plant diversity in pastures affected milk production and FA composition. In experiment 1, 18 Montbéliarde cows were split into 3 groups and grazed pastures of differing plant diversity. Cows did not receive any concentrate supplementation (grass-only). Cows grazed during day and night by strip grazing using electric fences that were moved forward every two days. The 3 different pastures are described in the table above. One pasture supported 17 plant species, the second pasture listed had 31 species, and the third pasture 50 plant species. Grasses dominated the pastures with 17 and 31 plant species with a ground cover over 70%. The highly biodiversified pasture in Experiment 1 had a lower grass ground cover of 52%. The legume contribution to the ground cover was low in all 3 pastures. Most of the other species listed are forbs of varying utility as forages. Although there is a diversity of plant species (species richness), most are of little importance because they contribute so little to the forage biomass. Yet, they do occupy space that could grow another plant species that would benefit the grazing animal and its production more.

Pasture biodiversity and milk yield and fatty acid profile

FA, g/100 g	Lower[1]	Medium[2]	Higher[3]	SEM	*P*
Milk yield, kg/d	16.3	17.9	14.0	0.38	<0.01
c-9 18:1	21.7	18.9	24.9	0.42	<0.001
c-9, *c*-12 18:2	0.86	0.77	1.19	0.03	<0.001
ALA	0.63	0.59	0.79	0.02	<0.05
t-11 18:1	3.13	3.12	2.81	0.13	NS
c-9, *t*-11 CLA	1.95	1.77	1.48	0.08	NS

[1]Lower biodiversity = 17 plant species
[2]Medium biodiversity = 31 plant species
[3]Higher biodiversity = 50 species
Coppa et al. (Anim. Feed Sci. Technol., 2015 208:66–78)

University of New Hampshire

The medium biodiversity pasture had the highest milk production trailed by the lower biodiversity pasture. Both have a strong grass component with a 7 percent ground cover of white clover, and vetch in the medium diversity pasture. The higher diversity pasture had only 52% grass ground cover and little clover. 46% of the ground cover was assorted forbs. Species richness can be high, but populated with many low producing unplanned plants that may be avoided entirely by the grazing animal. It is clear in this experiment, milk production suffered. Most of the intake is coming from cool season grasses and when low in quality (late maturity grasses grazed at times), the forbs present are not a substitute. A higher legume component (25% by weight) would go a long way to produce more milk. Lesson here is that species richness has little to do with improving pasture forage production. The curious thing in the figure above is the depression of the FA oleic acid (c-9 18:1), linoleic acid (c-9, c-12 18:2), and ALA at the medium diversity pasture. Meadow foxtail replaces the perennial ryegrass found in the lower diversity pasture. However, it is nearly as digestible as perennial ryegrass so it is unlikely to be the problem. Several other grasses are also present in the medium diversity pasture and may make up more of the grass component that can be ascertained from the table above. None of the herbs present in the medium diversity pasture are harmful except for being not very productive. The higher diversity pasture produced milk with the highest levels of oleic acid, linoleic acid, and ALA. The omega-6 to omega-3 ratio in the milk again is below 4.0 running from 1.31 at medium diversity to 1.51 at the higher diversity pasture. Vaccenic acid (VA) and CLA levels in milk trended lower as plant diversity increased, but was not statistically significant.

Summary

Three salient findings were found in this review of the literature:

- Increased pasture allowance improved milk yield, but inconsistent effect on milk CLA.
- Replacing pasture with concentrate reduced milk CLA, but increased milk yield.
- Increasing pasture biodiversity (species richness) seems to improve milk oleic, linoleic, and ALA consistently, but variable responses on milk VA and CLA.

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