Nutritional Practices to Reduce the Environmental Impact of Grazing Beef Cattle[1,2]

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Introduction

The effects of beef cattle operations on water and air quality, climate change, wildlife, and the general environment is a growing concern. Native and improved grasslands are a vital component of the beef cattle production system and cattle are an efficient means to convert forages to high quality human food. With increased concern about the environment, many "common" practices might need to be revised to balance production efficiency with real and perceived environmental concerns (i.e., manage for optimum, rather than maximum, production).

Beef cattle excrete 80 to 90% of the nutrients they consume. In an average week, 100 head of grazing beef cows will excrete about 6,200 lb of dry manure, 200 lb of N, 40 lb of P, 95 lb of K, as well as other macro- and micro-minerals, and physiological active compounds such as natural and exogenous hormones. These excretions provide valuable nutrients to forages if distributed at optimum rates; but if over applied, can potentially runoff into surface waters, percolate into ground water, volatilize as ammonia (**NH_3**), be lost as greenhouse gases (**GHG**), or accumulate in soils. Nutrients applied in fertilizers can also be lost.

Environmental Challenge(s) Facing Cattle Producers

Water Quality Issues

The EPA currently designates large portions of U.S. and Florida waters as "impaired" and asserts that agricultural operations are a major source of the impairment (http://water.epa.gov/lawsregs/lawguidance/cwa/tmdl/index.cfm: http://iaspub.epa.gov/waters10/attains_state.control?p_state-FL). The greatest water quality concerns to livestock producers are generally losses of N and P, organic matter (as Biological Oxygen Demand - **BOD**), physiological active compounds, and pathogens (E. coli, Salmonella, etc.) to surface or ground waters.

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Water quality is generally regulated under the Clean Water Act (**CWA**, www.epa.gov/lawsregs/laws/cwa.html) and its amendments. The CWA established the National Pollution Discharge Elimination System (**NPDES**) for point-sources and Total Maximum Daily Loads (**TMDL)** for non-point sources (www.epa.gov/waters/ir). TMDLs are pollution limits set for a waterway based on its uses. Under TMDL, all dischargers of pollutants are required to share in controlling the pollution. (www.beefusa.org/floridanumericnutrientcriteria.aspx : www.floridacattlemen.org/d/fl_cow_calf_bmp_manual.pdf). Because water quality depends on so many factors, the specifics of TMDL for different waterways will vary.

Air Quality Issues

Air quality emissions of greatest concern to livestock producers vary with location and type of operation but in general are dust particles (total suspended particulates – **TSP**, PM-10, PM-2.5, and PM-coarse:), odors, NH_3, and GHG. These are frequently regulated at the federal or state level or are indirectly "controlled" via lawsuits and court orders.

Regulations. The Clean Air Act (**CAA**; www.epa.gov/air/caa) originally set National Ambient Air Quality Standards (**NAAQS**) for emissions of TSP and five other priority pollutants. Via amendment and court orders, this list has been expanded to include PM-10, PM-2.5, (www.epa.gov/pm), and some GHG (www.epa.gov/climatechange/endangerment.html; www.regulations .gov/search/search_results). The Emergency Planning and Community Right to Know Act *(***EPCRA***)* regulates emissions of several thousand "hazardous" emissions. Under EPCRA, any beef cattle Animal Feeding Operation (AFO) that emits more than 100 lbs of ammonia or hydrogen sulfide in a day are required to report their potential emissions.

Odors. Odors are a mixture of over 100 volatile organic compounds (including volatile fatty acids [**VFA]**, indoles, cresol, sulfurous compounds) produced by the microbial fermentation of carbohydrates and proteins in feces and urine and have different odor stabilities, intensities, and offensiveness (Parker et al., 2007). Odor issues tend to be limited to sources that are in close proximity to homes and businesses.

Ammonia. Ammonia is produced from N fertilizers and by the hydrolysis of urinary- urea. Net NH_3-N losses from pastures range from 10 to 30% of N intake (Bussink et al., 1996; Asman, 1998; Petersen et al., 1998; Hristov et al., 2011).

Greenhouse gases. The GHG of most importance to cattle producers are carbon dioxide (**CO_2**), methane (**CH_4**), and nitrous oxide (**N_2O**). Methane has 21 to 26 times the global warming potential (**GWP**) of CO_2, and N_2O has a GWP of 296 to 310 times that of CO_2. Because of differences in GWP, these gases are normally discussed based on their CO_2 equivalents (**CO_2e**). Agriculture contributes approximately 6.3% of all U.S. anthropogenic GHG emissions (EPA, 2011; USDA, 2011). Of that 6.3%, approximately half comes from livestock and their manure and much of the rest is N_2O emissions from soils (EPA, 2011).

Methane is produced by anaerobic fermentation in the digestive tract and in manure. About 80% of all U.S. beef cattle enteric CH_4 emissions are from the cow herd and about 12% are from stocker cattle (USDA, 2011). Grazing beef cows emit about 0.4 to 0.8 lb of enteric methane daily. This is equivalent to about 6.5% (range 5 to 8.5%) of gross energy intake (Johnson and Johnson, 1995; IPCC, 2006; EPA, 2011). Emissions of CH_4 from fresh feces on pastures average about 0.015 kg CH_4/kg of volatile solids (IPCC, 2006: EPA, 2011).

Nitrous oxide is formed from nitrification and denitrification of nitrogenous compounds in soils, feces and urine. The drained organic soils of Florida are potentially rich sources of N_2O; cultivated Florida soils produce about 6.5% of all U.S. soil emissions (USDA, 2011; CAST, 2011). Emissions of N_2O from manure and inorganic fertilizers average about 2% of excreted and applied N, respectively (IPCC, 2006; USDA, 2011).

Pollution Mitigation Strategies

Balancing Nutrient Inputs and Outputs

By balancing the quantity of nutrient inputs with outputs, the risk of nutrient losses to waters or the atmosphere is minimized. Under "native rangeland" conditions, N inputs from precipitation, gas absorption, and biological fixation dominate, thus the balances between nutrient inputs and outputs approach zero (Heitschmidt, et al., 1996). However, in more intensive operations where inputs of fertilizers and feeds dominate, the recovery of added fertilizer nutrients is relatively low (Table 1). When legumes are used, a considerable quantity of N can enter the system through N fixation (Kalmbacher, 1998).

Cattle Production Strategies

Under most conditions, the net gain/loss of nutrients through mature cows is close to zero. However, on average, fewer than 85% of cows produce a weaned calf each year and about 20% of cows are culled and replaced annually. Because of these factors, in the U.S. we have about 1.6 cows for each animal finished in feedlots (USDA-NASS, 2007). Dietary, genetic, and management regimens that increase the reproductive rate of the cow herd and/or decrease the time required for heifers to become productive, will: 1) decrease this ratio, 2) decrease unneeded use of resources, 3) decrease losses of nutrients, NH_3 and GHG, 4) decrease the overall C footprint of the beef herd, and 5) increase nutrient outputs in cattle sold.

In general, the quantity of N, P, and other nutrients removed when animals are sold is actually relatively small (Table 1). Nutrient outputs may be increased via supplementation and fertilization; however, use of technologies such as implants and ionophores can increase growth, P retention, and feed efficiency (Niemann et al., 2002) with minimal additional nutrient inputs.

Fertilizer Strategies

If improperly managed, significant quantities of applied fertilizer N and P can be lost to surface or ground waters, or to the atmosphere (Sharpley et al., 1996). Recommended fertilizer application rates in Florida vary with types of forage, grazing system, and forage management (Newman, 2011). Nitrogen needs of many grasslands can be efficiently met with modest N fertilizer additions or through legume-grass mixtures. Fertilizer inputs can be decreased and risk of losses can be minimized by using unfertilized buffer strips in areas immediately downwind of atmospheric N sources such as CAFOs (Hao et al., 2006; Todd et al., 2008), areas where animals tend to congregate, or 3) areas within 50 to 100 feet of riparian zones (Heathwaite et al., 1998). However, buffer strips must be properly managed in order to maintain their ability to capture nutrients (Andersen et al., 2011).

Soil tests can be misleading and result in over-application of P and K; therefore, they should be properly interpreted (Sumner et al., 1992; Hanlon, 1995) and combined with tissue P concentrations to determine if P applications are required (Newman, 2011).

Using data from four studies, I calculated the effects of fertilization strategy on N and P balance of a cow-calf operation (Table 1). Based on the assumptions presented in Table 1, in general, as fertilizer applications increased, the recovery of fertilizer nutrients in forage and the return on investment decreased. Excess fertilizer was detrimental to the whole farm nutrient balance and was not always profitable as only 3 to 12% of applied fertilizer nutrients were removed in animals that left the ranch. These nutrient recoveries are appreciably higher if all, or part, of the forage is cut for hay or silage. In an 11-year study of N fertilization of pastures, 36% of applied N accumulated in the forage tops, 28% accumulated in the litter and roots, 19% remained in the soil, 18% was lost to the atmosphere, and only 3% was removed in beef cattle (Stevenson, 1982).

Ammonia losses from fertilizer applications to pastures can range from 20 to 50% of the N applied depending upon soil pH, fertilizer applied, soil N, rainfall, wind, etc. Losses of N_2O can also be significant under some conditions, typically being greatest for poorly drained neutral soils with high organic matter content during warm weather (Stevenson, 1982). In theory, the intensively grazed grass-legume pasture is an almost ideal agricultural ecosystem (Stevenson, 1982). Kalmbacher (1998) noted greater daily gains by stocker cattle on grass-legume vs. bahiagrass pastures in 1 of 2 studies when stocking rates were constant.

Feed/supplement Inputs

Nutrient requirements of cows and calves vary with stage of production (NRC, 2000) and the quality of forage varies with stage of growth and season. The quality and/or quantity of forages frequently do not completely meet the animal's nutrient requirements; therefore, supplementation may be needed to optimize production. To minimize nutrient losses, the supplement(s) provided should balance the difference between animal requirements and the nutrients in the available forage (Table 2).

The supplements needed most often are minerals, protein (crude protein (**CP**), ruminally degradable intake protein (**DIP**), or ruminally undegradable protein (**RUP**)) and energy.
Mineral supplements should be formulated to balance for forage mineral content and animal requirements. Use of P in minerals should be limited to avoid excess P inputs. Moving mineral feeders frequently can help distribute grazing pressure and manure deposition.

Under some grazing conditions cows may require additional protein. Because natural protein supplements also contain P and K, protein supplementation may simultaneously increase the quantity of N, P, and K imported to the ranch and excreted by the cow herd. For example, in order to provide 1 lb of CP per day, the quantity of P potentially excreted by one cow over a 100-day supplementation period can range from about 0.8 to 5 lb (Table 3). However, feeding supplements that contain high concentrations of N, P and K could also potentially decrease the need for fertilizer N, P, and K. Nebraska studies using stocker calves on bromegrass pastures (Greenquist et. al., 2009, 2011) indicated that feeding 5 lb of dried distiller's grain daily increased beef production per acre similarly to fertilizing with 80 lb of N /ac; but with about 60% the N inputs (Table 4). For such a system to work over the long run, supplementation must be managed so as to distribute feces and urine over the entire pasture.

Florida studies (Hopkins et al., 1999; Davis, et al., 2000) suggest that ruminal escape methionine may be an important factor to consider in protein supplementation programs for cows. The research indicates that providing approximately 5 to 6 g of escape methionine daily, either in a commercial "bypass methionine" product or as corn gluten meal (2 to 5 lb/d) increases average daily gain of stocker calves by about 0.25 lb/d (Table 3). Some studies using "bypass" methionine in supplements for cows on native range grasses suggest that additional DIP might be needed in the supplement to avoid a ruminal ammonia deficiency (Lodman et al., 1990; Wiley et al., 1991). It is not clear whether added DIP is needed for cows or stockers grazing typical Florida forages. The degradability of protein in Florida forages is affected by fertilization and date of cutting, but even without fertilization the quality of most Florida forages appear to be adequate for cows during most of the year (Table 2: Johnson et al., 2001). Based on these results it might be possible to decrease the quantity of protein supplements fed to beef cows by feeding mixtures of bypass amino acids with natural proteins and/or non-protein N.

Providing cattle with adequate "bunk" space or numbers of feeders, feeding more frequently, and distributing feeders across pastures can lead to more uniform supplement intakes within the herd and, more even distribution of excreted feces and urine across pastures.

Decreasing gaseous emissions from pastures. Ammonia and N_2O losses on pasture occur primarily from N fertilizers and urinary N. Proper timing and rate of fertilizer applications can decrease ammonia losses. During some seasons of the year, the protein content of many forages will exceed the requirements of cows or stocker calves. Limiting CP intake to the animals' requirements, or providing an additional low protein energy source when forages are excessively high in CP can decrease N excretion and thus decrease NH_3 and N_2O losses.

Depending upon management, fertilization, and other factors, pastures can be a source, a sink, or both for CO_2e (USDA, 2011). The impacts of pasture-based beef production systems on net GHG emissions depends largely on a balance between organic C sequestration in plants and soils (**SOC**) with fluxes of CO_2, N_2O and CH_4 from soils, manure, and animals. The net ecosystem exchange of CO_2e in pasture soils is affected by climate, weather, soil, plant community, fertilization, burning, cutting, and grazing. Practices that increase forage production generally increase the ability of pastures to serve as C sinks; however, increased inputs of fertilizer or manure N can increase emissions of N_2O that negate C sequestration benefits of soils (CAST, 2011).

Some studies suggest an increase in SOC with rotational grazing (vs. continuous season long grazing); whereas, other studies suggest no difference (CAST,2011). The effects of cattle stocking rate on SOC are also variable; however, it appears that in managed pastures, SOC can be optimized by using a moderate stocking rate compared with no grazing or continuous heavy stocking (CAST, 2011). Proper livestock grazing, with optimum stocking rates, can sequester SOC at a rate exceeding that of Conservation Reserve Program (CRP) or hay land. Burning has the potential to alter SOC; however, burning grassland results in substantial loss of C to the atmosphere.

Ecosystems eventually reach a steady state in SOC, after which there is no increase in C sequestration. Thus, the greatest opportunity to increase pasture C sequestration is via improved management of depleted/poorly managed grasslands and cropland. Establishment of improved pastures on degraded, formerly cropped soils can sequester SOC at rates over 2 times that of no-till farming (CAST, 2011), improve soil and water quality, or serve as sources of C-credit.

Decreasing enteric methane emissions. Enteric CH_4 emissions from cattle operations are not currently regulated; however, they can represent a significant energy loss from the animal. Additionally, in the future, mitigation strategies may also become a potential C-credit source that can bring additional income to the producer.

A number of nutritional strategies and dietary additives (tannins, yeasts, enzymes, dicarboxylic acids, saponins, halogenated compounds, ionophores) decrease enteric methane emission from cattle for short periods of time (Table 5). However, their long-term effectiveness and impact on economic returns have not been adequately tested. Currently, the nutritional strategy that appears most feasible is the feeding of fat – either as a supplement ingredient (tallow, etc.), or as a component of a supplement ingredient (whole cottonseed, etc.). Dietary fats decrease CH_4 production by 3 to 6% for each 1% fat in the diet – with a maximal effect at about 7% dietary fat (Beauchemin et al., 2008; Martin et al., 2010). For example, feeding 4 lbs of whole cottonseed will increase fat intake about 0.75 lb/d (Table 3) and theoretically decrease enteric CH_4 production by 10 to 20%.

Summary of Possible Solutions to the Challenges

1. Minimize, as much as possible, the purchase and importation of feeds to the farm.

A. Use protein and mineral sources that efficiently meet animal requirements
B. Avoid supplements that are high in P and (or) K except when required by the animals.
C. Use judicious selection of breeding herd and breeding program to match cow size and milking potential to available resources.
D. Adapt "precision grazing" by providing stockers and growing cattle access to the "best" forage thereby limiting access of cows to forage with nutrient composition that far exceeds their requirements. Sort cows and heifers to pasture based on nutrient requirements.
E. Provide supplements so that intake is evenly distributed across the herd and across the pastures.

2. Minimize the purchase and import of fertilizers to the farm.
A. Conduct soil and forage tests to assist in monitoring nutrient use and needs.
B. Use "precision agriculture" in planning fertilization: avoid locations with high animal density, in close proximity to surface waters, and with hydrological access to ground waters (wells, springs, etc.)
C. Properly calibrate fertilizer equipment
D. Use Fertilizer Best Management Practices.

3. Maximize recovery of nutrients in forages through a combination of grazing and haying, intensive grazing strategies, use of legumes, etc.

4. Make use of technologies that increase beef production without adversely affecting nutrient management (implants, etc.)

5. Minimize erosion and runoff
A. Maintain adequate vegetative cover
B. Do not supply feed and minerals within 100 feet of wetlands
C. Develop alternative water sources other than streams, ponds, etc.
D. Locate temporary holding areas such as calving facilities at least 200 feet from surface waters and use filter strips, berms, etc. to prevent runoff to surface waters and offsite discharge.

6. Become informed and knowledgeable about critical issues in your water- and air-shed

7. Develop a written ranch conservation plan. (See www.dep.state.fl.us/water/sperp/nonpoint_storm)

8. Properly train employees

9. Critically analyze costs and evaluate options to minimize losses.

A. Two factors critically important to the profitability of a cow-calf operation are calving percentage and weaning percentage (Dunn et al., 2001). They are also critically important for optimum nutrient balances.

10. Follow water quality best management practices for Florida (www.floridacattlemen.org/d/fl_cow_calf_bmp_manual.pdf).

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Table 1. Calculated effects of fertilizer application on N and P balance and cost of production of a 362-acre bahiagrass-based cow-calf ranch assuming no hay production

	Fertilizer applied annually, lb N / acre				
Item	0	30	60	120+P&K	180+P&K
Forage, lb DM/acre	6,620	7,613	8,606	9,600	10,590
Increase in forage, %	-	15	30	45	60
Acres/cow-calf unit	3.62	3.15	2.79	2.50	2.26
Number of cows	100	114	130	145	160
Total N applied, lb	0	10,860	21,720	43,440	65,160
Total P applied, lb	0	0	0	7,240	14,480
N removed in livestock, lb	1,110	1,266	1,444	1,611	1,776
% of fertilizer N	--	11.6	6.6	3.8	2.7
P removed in livestock, lb	555	633	722	806	888
% of fertilizer P	--	--	--	11.1	6.1
Fertilizer cost					
N, at $0.72 / lb of N	0	7,819	15,638	31,277	46,915
P, at $0.82 / lb of P	0	0	0	6,154	12,308
Total	0	7,819	15,638	37,431	59,223
Cattle sales, $	57,000	64,480	74,100	82,650	91,200
Increase over no fertilizer	--	7,980	17,100	25,650	34,200
$ Return / $ of fertilizer	--	1.02	1.09	0.68	0.58

Forage yield and effects on production with fertilization based on averages of Sumner et al (1992), Rechcigl and Mucohovej (1998), Jennings (1995), and Johnson et al. (2001).

Assumptions: 1) each cow-calf unit requires approximately 24,000 lb of DM annually - 12,000 lb / 50% harvesting efficiency, 2) an 80% calf crop weaned, 3) cow sell weight of 1,100 lb, steer sell weight of 550 lb, and heifer sell wt of 500 lb, 4) cows sold at $ 70/cwt and feeder calves at $ 130/cwt, 5) 20% of cows replaced annually with heifers from the same herd, and 6) animals average 1% P on an as-is basis and 1.75 (heifers), 2 (steers), or 2.25% (cull cows) N on an as-is basis.

Table 2. Nutrient requirements of cows during the year and bahiagrass forage composition

		Cow requirements				Bahiagrass, % DM	
Month	Stage of production	DMI lb/d	TDN (%)	CP lb/d or (%)	P (%)	TDN	CP
Jan	last 1/3	19.6	54	1.6 (8.0)	0.16	46	7
Feb	Calving	19.6	54	1.6 (8.0)	0.16	46	7
Mar	Calving	20.0	58	2.0 (9.6)	0.22	46	7
Apr	Calving	20.0	58	2.0 (9.6)	0.22	53	10
May	Lactating	20.0	58	2.0 (9.6)	0.22	53	10
June	Lactating	20.0	58	2.0 (9.6)	0.22	53	10
July	Lactating	18.1	56	1.3 (7.0)	0.18	53	10
Aug	Lactating	18.1	56	1.3 (7.0)	0.18	53	10
Sept	Lact/Wean	18.1	56	1.3 (7.0)	0.18	53	10
Oct	Weaning	18.1	54	1.3 (7.0)	0.18	53	10
Nov	Last 1/3	19.6	54	1.6 (8.0)	0.16	53	10
Dec	Last 1/3	19.6	54	1.6 (8.0)	0.16	53	10

Based on Florida studies cited in Table 1, P concentration of bahiagrass ranges from 0.17 to 0.31% of DM and K concentration ranges from 0.41 to 0.95% of DM. Potassium requirement of cows is approximately 0.6% to 0.8% of DM.

Table 3. Quantity of feed fed daily, total TDN intake, and total N, P and K excreted (lb/cow) over a 100-day supplementation period to obtain intakes of 1 lb of crude protein or 5 g of methionine / day

	To obtain 1 lb of CP					
Feedstuff	Fed, lb/d	N, lb/hd	P, lb/hd	K, lb/hd	TDN intake, lb/hd	Fat intake, lb /day
Bahiagrass	11.2	16	2.47	16.3	7,275	0.23
Citrus pulp	14.9	16	1.94	11.5	12,218	0.55
Corn gluten meal	2.13	16	1.1	0.9	183	0.05
Cottonseed meal	2.17	16	2.5	4.0	169	0.07
Dry distiller's grain	4.00	16	3.0	2.4	352	0.37
Feather meal	1.16	16	0.8	0.23	81	0.08
Fish meal	1.47	16	4.6	0.52	103	0.16
Gin trash	13.51	16	1.62	16.2	892	0.23
Peanut skins	5.74	16	1.15	11.5	172	1.46
Soybean hulls	8.18	16	1.48	2.54	524	0.17
Soybean meal	2.00	16	1.4	4.65	168	0.03
Wheat midds	5.43	16	5.43	6.03	375	0.17
Whole cottonseed	4.16	16	2.58	5.16	399	0.75
Supplement	To obtain 5 g of "bypass" methionine/day					
Corn gluten meal	1.81	13.6	0.9	--	1.56	0.04
Cottonseed meal	8.82	65.0	10.2	--	6.86	0.26
Feather meal	3.74	51.4	2.54	--	2.61	0.27
Fish meal	0.95	10.3	3.0	--	0.67	0.10
Soybean meal	6.24	49.8	4.4	--	5.24	0.10
Whole cottonseed	1.75	42.0	1.1	--	1.45	0.31

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Table 4. Effects of N fertilization (80 lb N/acre) or supplementation (5 lb dried distillers grains daily) strategy on forage quantity, performance, and N utilization of calves on smooth bromegrass pastures (Greenquist et al., 2009, 2011)

	Treatment			
Item	Control	Fertilizer only	Supplement only	SEM
Standing forage, lb/acre	2,056a	2,431b	2,213a	115
Stocking rate, AUM/acre	3.5	5.41	5.65	0.48
Supplement intake, lb/d	0	0	5.0	--
Forage intake, lb/d	18.9a	18.8a	14.4b	0.12
BW gain, lb	242a	238a	323b	7
BW gain, lb/acre	176a	270b	361c	6
Daily gain, lb/d	1.50a	1.47a	2.02b	.04
N from DDGS , lb/hd	0	0	39.0	--
N from forage, lb/hd	73.4a	83.0b	59.3c	2.0
Total N intake, lb/hd	73.4a	83.0b	98.3c	2.0
N excreted, lb/hd	67.0a	76.6b	89.9c	2.0
N from DDGS, lb/acre	0	0	43.7	--
N from fertilizer, lb/acre	0	80.0	0	--
Dry deposition, lb/acre	5.8	5.8	5.8	--
Total N inputs, lb/acre	5.8a	85.8c	49.5b	3.2
Forage N consumed, lb/acre	54.0a	93.6b	66.2c	5.6
N excreted, lb/acre	49.3a	86.4b	100.6c	5.1
N input – retention	1.09a	78.9b	40.1c	0.35
N retained,% of inputs	81.2a	8.33b	19.12c	3.63

DDGS – dried distillers grains with solubles.

[a,b,c] Values in same row with unlike superscripts differ, ($P < 0.05$).

Table 5. Summary of effects of various dietary strategies on enteric methane production of cattle based on modeled simulations and research comparisons

Strategy	CH_4, % of GE Intake	CH_4, % of DE intake
Increasing DM intake	-9 to -23%	-7 to -17%
Increasing concentrate to roughage ratio	-31%	-40%
Beet pulp vs. barley	-24%	-22%
Rapid vs. slowly degraded starch	-16%	-17%
Increased forage maturity	+15%	-15%
Legume vs. grass	+28%	-21%
Dried vs. ensiled forage	-32%	-28%
Increased forage processing	-21%	-13%
Supplementation of straw	x 3	x 1.5
Fat supplementation	-25%	-30%
Feeding monensin (30 days)	-10%	-10%

GE = gross energy, DE= digestible energy.

Adapted from Benchaar et al. (2001), Lovett et al. (2003), Guan et al. (2006), Beauchemin et al. (2008) and Martin et al. (2010).

SESSION NOTES