Nutrient Requirements of Grazing Dairy Cattle as Determined by the 2001 NRC[1]

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About every 10 years, the National Research Council (NRC) appoints a subcommittee to review the scientific literature and use the new information to revise the nutrient requirements of dairy cattle. In 2001, the NRC published the Seventh Revised Edition of the Nutrient Requirements of Dairy Cattle. The new revision includes requirements for energy, protein, minerals, and vitamins of calves, growing heifers, dry cows, and lactating cows. The book also presents recommendations for carbohydrate fractions (adult cows only), equations to estimate dry matter (DM) intake (growing heifers, dry cows, and lactating cows), and information on health disorders related to improper nutrition. A major component of the new edition is a computer program that can be used to evaluate the ability of a diet to meet the nutrient requirements of a specific animal. A detailed discussion of all nutrients for all classes of dairy cattle is beyond the scope of this paper. Rather, this paper will discuss only adult lactating cows and how grazing affects nutrient requirements and diet formulation.

The approach followed by NRC is to first estimate requirements on a biologically available basis. Biologically-available means that the nutrient is available to a cell or tissue to be used for productive purposes. The second step is to determine the supply of biologically available nutrients provided by a given diet. For example, an average Holstein cow producing 70 lbs of milk needs to absorb about 55 g of phosphorous per day. The bioavailability of phosphorous for a given diet may be 0.75. Therefore, to meet the P requirement, this cow would need to eat 55 g divided by 0.75 or 73 g of P per day. The requirements for biologically-available nutrients are a function of the cow (body weight, milk production, reproductive status), and nutrient supply is a function of the ingredients in the diet, DM intake, and the composition of the total diet.

The only biologically-available nutrient requirement known to be influenced by grazing is that of energy. Including pasture in diets, however, can affect the bioavailability of several nutrients.

Energy Requirements

Energy requirements and dietary concentrations are expressed in net energy for lactation (NEL) units. Cows require NEL to maintain themselves, to produce milk, and for

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fetal growth and development. The NEL required for these function are the same whether a cow is grazing or housed in confinement. The maintenance requirement is a function of body weight (BW): NEL for maintenance, Mcal/day = 0.07x $BW^{0.75}$ where BW is in kilograms (for example a cow with a BW of 1400 lbs or 636 kg has a maintenance requirement of 8.9 Mcal/day). That term was derived for cows under specific experimental conditions and must be adjusted to account for normal activity of a cow. For confinement cattle the maintenance (including normal activity) requirement is 0.08 x $BW^{0.75}$ or 10.1 Mcal/day for a 1400 lb cow. Grazing cattle, however, expend more energy gathering food and walking than do cows housed in confinement systems. The amount of NEL used for grazing activities is a function of BW, pasture intake, distance the cow walks, and the topography of the pasture (Table 1). In field situations, reliable estimates of BW and pasture intake can be obtained, but distance walked and topography are very difficult to quantify. The NRC (2001) developed equations to estimate NEL used for grazing activities that are functions of BW, distance walked between the paddock and the parlor, and on a qualitative assessment of topography ('flat' or 'hilly'). In addition the equations assume that intake is normal for a given BW and that the diet is approximately 60% pasture. This approach was taken because it was assumed users would not have reliable estimates of distance walked within a paddock or a quantitative measure of the change in elevation walked by the cow. Overall, the estimates for NEL requirements associated with grazing are less accurate than other requirements because of the necessary assumptions and limited inputs.

Table 1. Estimated (NRC, 2001) NEL requirements (Mcal/day) associated with grazing flat or hilly ground for an average Jersey cow (1000 lbs) and an average Holstein cow (1400 lbs).

Total distance, parlor to paddock, miles/day	BW = 1000 lbs		BW = 1400 lbs	
	'Flat'	'Hilly"	'Flat'	'Hilly'
0.25	0.63	3.33	0.88	4.66
0.50	0.71	3.41	0.99	4.77
0.75	0.79	3.49	1.11	4.89
1.00	0.88	3.58	1.23	5.01
1.25	0.96	3.66	1.34	5.12
1.50	1.04	3.74	1.46	5.24
1.75	1.12	3.82	1.57	5.35
2.00	1.21	3.91	1.69	5.47

The NEL requirement for activity associated with grazing ‘flat’ ground by lactating cows is calculated as: NEL (Mcal/day) = (0.00033 x BW x miles) + (0.000545 x BW) where BW is in pounds and miles = total distance the cow walks between the paddock and the parlor. The first term accounts for NEL used for walking and the second term is for NEL expended during grazing. For example, if the paddock is 0.3 miles (approximately 1580 ft) from the parlor and a 1400 lb. cow makes two round trips daily (total distance = 4 one-way trips x 0.3 = 1.2 miles), grazing activity will require (0.00033 x 1400 x 1.2) + (0.000545 x 1400) = 1.3 Mcal of NEL/day (that amount of energy is equivalent to the energy in about 4 lbs of milk). More energy is expended walking up hills than walking on flat ground. The NRC defined ‘hilly’ terrain as one in which cows walked a total of 200 meters (660 ft) in vertical distance. This is equivalent to a cow walking up a 330 ft hill twice a day. The NEL required to walk 660 vertical feet is 0.0027 Mcal/lb of BW. Therefore, the NEL requirement (Mcal/day) for a cow grazing a ‘hilly’ pasture is: (0.00033 x BW x miles) + (0.000545 x BW) + (0.0027 x BW) where miles = total distance walked between the paddock and parlor and BW is in pounds. For example, the grazing activity requirement of a 1400 lb cow that walks 1.2 miles between the paddock and parlor on hilly terrain is: (0.00033 x 1400 x 1.2) + (0.000545 x 1400) + (0.0027 x 1400) = 5.1 Mcal/day (equivalent to the energy in about 15 lbs of milk). In reality, ground is rarely perfectly flat and rarely as hilly as defined by NRC, actual requirements will probably be somewhere between the values obtained for ‘flat’ and ‘hilly’ topography. The NEL used for grazing is added to the NEL required for maintenance, for milk production and for gestation (if cows are pregnant) to obtain total daily NEL requirement.

Bioavailability of Nutrients from Pasture

Energy Supply. Biologically available energy is defined as NEL. The concentration of NEL in diets is mostly a function of the nutrient composition of each ingredient, total DM intake, and nutrient composition of the total diet. The first step is to estimate energy in each ingredient of the diet using equations based on the concentrations of neutral detergent fiber (NDF), lignin, ash, fat, and crude protein in the feedstuff. The energy value obtained is referred to as energy at maintenance (i.e., estimated energy if the cow was fed only enough energy to maintain herself). Total DM intake and the energy concentration of the total diet is used to ‘discount’ the maintenance energy value to an energy value obtained at productive levels of energy intake. Because digestibility decreases as intake increases, energy values at maintenance can be substantially higher than what is observed when lactating cows consume large amounts of energy. Table 2 shows expected NEL concentrations of high quality pasture at different intakes.

Protein supply. Protein requirements are given in metabolizable protein units. Dietary protein is divided into rumen degradable (RDP) and rumen undegradable (RUP) protein. Protein that is broken down in the rumen is RDP and protein that escapes (or bypasses) rumen digestion is RUP. Cows cannot use RDP directly, however, rumen bacteria need RDP and protein synthesized by rumen bacteria from RDP is a major source of protein for a cow. Diets deficient in RDP can reduce rumen fermentation, fiber digestion, feed intake, and milk production. Conversely, any RDP that is not used by bacteria to make bacterial protein is wasted (i.e., excess RDP provides no metabolizable protein). The RUP, if it is digested in the small intestine, is absorbed by the cow and supplies amino acids for maintenance of the cow and milk production. The NRC developed equations using in situ data to estimate RDP and RUP of feeds. This assay is not commonly done by commercial feed testing labs and most people will have to use the data for pasture published in the NRC. Feed protein is divided into rapidly soluble protein ('A' fraction), the potentially degradable fraction ('B' fraction) and the undegraded fraction ('C' fraction). Rate of digestion is also measured using in situ techniques. Feeds with large A fractions, and feeds with large B fractions and a rapid rate of digestion have high concentrations of RDP. Feeds with large C fractions or feeds with large B fractions with slow rate of digestion have large RUP concentrations. Besides in situ characteristics of a feed, DM intake affects RDP and RUP concentrations of pastures (Table 3). On average, the protein in pasture is less degradable than the protein in hay or silage.

Table 2. Estimated (NRC, 2001) NEL concentrations (Mcal/lb of DM) of pasture fed with different amounts of concentrate and at different total DM intakes. Estimated NEL content of total diet is in parenthesis[1].

	Total DM Intake, lbs/day			
Grain[2], lbs/day	35	40	45	50
10	0.73 (0.77)	0.72 (0.76)	0.71 (0.74)*	Not feasible
15	0.72 (0.78)	0.71 (0.76)	0.70 (0.75)	0.69 (0.73)*
20	0.71 (0.79)	0.70 (0.77)	0.69 (0.75)	0.68 (0.74)
25	Not feasible	0.69 (0.78)**	0.68 (0.76)	0.67 (0.74)

[1] Values are essentially the same for high quality cool season grasses and high quality legumes. The high quality grass contained (DM basis) 46% NDF, 2.1% lignin, 26% crude protein, and 9.8% ash. High quality legume pasture contained 33% NDF, 5.4% lignin, 26% crude protein, and 10% ash.

[2] Amounts are as-fed. Grain mix was 83% ground corn, 15% soyhulls, and 2% minerals.

* These diets may not be feasible. High intake with limited concentrate is difficult to achieve.

** This diet may not be adequate in fiber and rumen acidosis problems could occur.

Table 3. Estimated (NRC, 2001) degradability of crude protein (% of total crude protein) in medium and high quality grass and legume pastures at different total DM intakes. Composition data for high quality grass and legume pastures are from NRC (2001). Medium quality pastures reflect expected changes in protein fractions with increased maturity.

	Total DM Intake, lbs/day			
	35	40	45	50
High quality grass pasture	23.1	23.7	24.3	24.8
Medium quality grass pasture	29.1	29.7	30.4	31.0
High quality legume pasture	24.1	24.6	25.2	25.7
Medium quality grass pasture	29.1	29.6	30.4	31.0

Mineral supply. The NRC assigned absorption coefficients for most individual minerals depending on source. No data were available specifically for minerals provided by pasture, therefore values for haycrop silage were used for pastures. For most minerals this approach is probably acceptable, but a few important exceptions exist. The availability of magnesium is influenced by the potassium concentration of the total diet, and pasture often contain very high concentrations of K. The availability coefficient for Mg in pasture may be too high and pasture-based diets may need additional Mg supplementation. Copper in diets based on pasture has a lower than expected bioavailability. This low bioavailability is thought to be caused by ingestion of soil. Soil ingestion can reduce the availability of Cu in the total diet by as much as 50%. The NRC software does not include this adjustment, however, users should reduce the absorption coefficient for Cu from all feedstuffs in the diet by 25 to 50% when pasture is fed. For basal feeds the absorption coefficient for Cu is 0.04 and for Cu sulfate (common source of supplemental Cu) the coefficient is 0.05. For pasture-based diets these coefficients should probably be 0.02 to 0.03 for feeds and 0.025 to 0.037 for copper sulfate.

Vitamins. The NRC gives requirements for vitamins A, D, and E. These requirements are for supplemental vitamins, not for total diet concentrations. Because pasture usually contains much higher concentrations of B-carotene (precursor for vitamin A) and vitamin E than hay or silage, and vitamin D synthesis is higher for cows housed outside than for those in confinement, the NRC requirements for vitamins for cows on pasture are probably excessive. The software includes an adjustment based on expected vitamin E concentration of pasture for vitamin E requirements for pasture-fed cows. No adjustment is included for vitamins A and D. Diets that provide about 70,000 IU/day of supplemental vitamin A, 25,000 IU/day of supplemental vitamin D, and 125 IU of supplemental vitamin E should be more than adequate for grazing cows.

Evaluation of pasture-based diets using NRC

Several simulations with the NRC software were conducted using different inputs to illustrate NEL and protein supply and requirements for grazing cows. The results are applicable for the inputs that were used. Nutrient concentrations of the pasture, DM intake, and type of supplements used will affect the results. For simplicity mineral and vitamin information is not discussed. Pasture DM intake was estimated using an equation (Valquez and Smith, 2000).

<u>Grass pasture example.</u> Holstein cow (1400 lbs body weight) in midlactation grazing a grass-based pasture with a grain mix that was 83% ground corn, 15% soybean hulls, and 2% minerals. The distance between the parlor and paddock was set at 1000 ft and the cow made two round trips per day (flat ground). Results are shown in Table 4. Based on NRC (2001) a cow producing 50 lbs of milk/day (3.7% fat) consuming high quality grass pasture would need approximately 8 lbs (as-fed) of the grain mix to be in NEL balance (no change in body condition). That diet would provide enough metabolizable protein to produce about 55 lbs of milk. A cow producing 70 lbs of milk would need to consume about 16 lbs of grain mix to be in energy balance and that diet would provide enough metabolizable protein to produce about 70 lbs of milk. Based on NDF content of the diet, the maximum amount of concentrate that should be fed is about 28 lbs/day (assuming concentrate is fed twice daily). At that concentrate intake, metabolizable protein would limit milk production at about 82 lbs.

<u>Legume pasture example.</u> Holstein cow (1400 lbs body weight) in midlactation grazing a legume-based pasture with a grain mix (83% ground corn, 15% soybean hulls, and 2% minerals). Distance between the parlor and paddock was set at 1000 ft and the cow made two round trips per day. Results are in Table 5. Based on NRC, cows grazing a legume pasture needs almost no grain to maintain energy balance and produce 50 lbs of milk. At 70 lbs of milk, approximately 9 lbs of grain mix would be needed to maintain NEL balance (metabolizable protein would be adequate for 74 lbs of milk). Setting maximum concentrate intake at 28 lbs/day, metabolizable protein would limit milk production at about 92 lbs. If 1 lb of the corn in the grain mix was replaced with 1 lb of heat-treated soybean meal, the diet would provide enough metabolizable protein to support about 98 lbs of milk.

General Conclusions

Based on the NRC model (and most of the experimental data) cows grazing a grass pasture require substantial supplementation with concentrate to maintain energy balance at moderate milk production. With legume pastures, energy balance can be maintained with less concentrate. For both grass and legume pasture, a simple concentrate mix with no supplemental sources of protein fed at about 24 lbs/day can support 76 (grass) to 81 (legume) lbs of milk. Assuming a maximum concentrate feeding rate of 28 lbs/day, metabolizable protein will limit production at 82 to 92 lbs of milk production. Intake of NEL, not metabolizable protein, usually limits milk production except in early lactation and for very high producing cows.

Table 4. Evaluation of different diets containing high quality grass pasture using NRC (2001). The base cow weighed 1400 lbs and was in midlactation. The column labeled energy balance is for a diet with enough concentrate so that estimated NEL balance (intake - requirements) was 0.

	Energy balance (EB)	EB + 8 lbs of concentrate
50 lbs of milk/day		
Est. pasture intake[1], lbs DM/day	31.0	31.7
Concentrate intake, lbs as-fed/day	8	16
Total intake, lbs DM/day	38.2	46.1
Met. protein allowable milk, lbs/day	55	68
NEL balance, Mcal/day	0	5.7
70 lbs of milk/day		
Est. pasture intake, lbs DM/day	32.8	30.1
Concentrate intake, lbs DM/day	16	24
Total intake, lbs DM/day	46.9	51.6
Met. protein allowable milk, lbs/day	70	76
NEL balance, Mcal/day	0	2.3
82 lbs of milk/day (max. based on protein supply at maximum safe concentrate level)		
Est. pasture intake, lbs DM/day	29.5	. . .
Concentrate intake, lbs DM/day	28	. . .
Total intake, lbs DM/day	54.7	. . .
Met. protein allowable milk, lbs/day	82	. . .
NEL balance, Mcal/day	0	. . .

[1] Pasture intake estimated using an equation (Vazquez and Smith, 2000).

Table 5. Evaluation of different diets containing high quality legume pasture using NRC (2001). The base cow weighed 1400 lbs and was in midlactation. The column labeled energy balance is for a diet with enough concentrate so that estimated NEL balance (intake - requirements) was 0.

	Energy balance (EB)	EB + 8 lbs of concentrate
	50 lbs of milk/day	
Est. pasture intake[1], lbs DM/day	37.8	39.2
Concentrate intake, lbs as-fed/day	1	9
Total intake, lbs DM/day	38.8	47.2
Met. protein allowable milk, lbs/day	58	72
NEL balance, Mcal/day	0	6.4
	70 lbs of milk/day	
Est. pasture intake, lbs DM/day	40.3	37.6
Concentrate intake, lbs DM/day	9	17
Total intake, lbs DM/day	48.4	52.9
Met. protein allowable milk, lbs/day	74	81
NEL balance, Mcal/day	0	3.2
92 lbs of milk/day (max. based on protein supply at maximum safe concentrate level)		
Est. pasture intake, lbs DM/day	35.4	. . .
Concentrate intake, lbs DM/day	28	. . .
Total intake, lbs DM/day	60.6	. . .
Met. protein allowable milk, lbs/day	92	. . .
NEL balance, Mcal/day	0	. . .

[1] Pasture intake estimated using an equation (Vazquez and Smith, 2000).

References

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