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Review

Influence of Dietary Fiber on Feed Energy Usage by Ruminants

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ABSTRACT

Fiber content and its digestibility are the primary factors determining digestible energy content of feeds. Depression of digestible energy at high levels of intake is associated mainly with reduced fiber digestion. At high intake, methane production is associated with amount of digestible cellulose, but at maintenance intake levels, it is determined mainly by total digestible dry matter. High fiber diets result in a high molar proportion of acetate, which is used less efficiently than propionate or butyrate for fattening. However, efficiency of acetate use depends on the type of basal diet. High fiber diets have higher eating and ruminating energy costs. Eating and ruminating times are enhanced by increased dietary neutral detergent fiber content. Some researchers have suggested that work of digestion for high fiber diets might account for an appreciable amount of heat increment. In general, high fiber diets have a lower utilization efficiency of metabolizable energy for maintenance or production than low-fiber diets.

Key Words: Gross energy; Digestible energy; Metabolizable energy; Ruminants; Fibrous diets

Fibrous feeds contain some unavailable fiber fractions and thus, regulate feed digestibility. Fiber fractions also dictate energy expenditures that influence efficiency of metabolizable energy (ME) utilization of feeds (Van Soest, 1982). Ruminants require an adequate amount of dietary fiber for normal rumen function and milk fat production (Van Soest, 1980). Mertens (1983) found a quadratic relationship of 4% fat corrected milk yield with neutral detergent fiber (NDF) content of the ration in dairy cows producing about 20 kg milk/day. Maximum fat-corrected milk yield occurred when rations contained 35% NDF on a dry matter (DM) basis. This optimum NDF content was same for diets with alfalfa, corn silage or bermuda hay. Colenbrander *et al.* (1986) reported that rations containing 32% NDF also were adequate for cows in early lactation producing 30 kg/d of fat-corrected milk. Quigley *et al.* (1986) reported that acid detergent fiber (ADF) and NDF decreased as ration energy content increased; however, maximum digestible energy (DE) intake was observed when ADF in the ration was 16% or NDF was 40 to 44%. These data show that increasing dietary fiber content beyond optimum level reduces animal performance. Therefore, the purpose of this paper is to discuss the effect of fiber content of ruminants diets on energetic efficiency.

Digestible Energy

Apparent fecal energy losses range from 15% in grains to 55% in straw (MAFF, 1976). Apparent DE is associated with *in vivo* DM or organic matter digestibility (Fonnesbeck *et al.*, 1981; Seoane, 1982). Therefore, discussion of fiber effects on DE are assumed to be the same as for *in vivo* forage digestibility. NDF contains all of the truly indigestible components of feeds. However, it is poorly associated with digestibility. Van Soest (1978) concluded that the relationship between digestibility and cell wall content is limited because of variation in the cell wall digestibility. The relationship between DM digestibility and cell wall digestibility varies among plant species (Sarwar *et al.*, 1995; Garcia, 1984) The relationship between cell wall digestibility and DM digestibility may work well for grasses, which have higher amounts of cell wall; however, in plants with lower cell wall content, this association may be less consistent.

The ADF fraction is more closely related to forage digestibility over a wide range of forges than is NDF content (Van Soest, 1982), which is probably because ADF represents less digestible fractions of the cell wall. However, the intended use of ADF is as a preparative residue for determination of cellulose, lignin, unavailable nitrogen and silica (Van Soest & Robertson, 1979) Thus, the use of ADF as an indicator of digestibility is not found on any theoretical basis other than statistical association (Van Soest & Mertens, 1977). Mitchell (1973) demonstrated that this relationship was different for grass diets than for clover diets. Moreover, Seoane (1982) did not find a significant association between ADF content and DM digestibility when grass and legume diets were included in the analysis, an observation that may be attributed to the variation in ADF composition. However, variation in ADF composition within plant species is smaller and thus, related more highly to forage digestibility. Van Soest (1965) showed that ADF was associated highly with DM digestibility within legume or grass species but not between species.

Lignin is the major factor limiting availability of cellulose to ruminal bacterial degradation (Sarwar *et al.*, 1996). Jung and Vogel (1986) showed that lignin inhibits cell wall digestion to a greater extent than it affects total forage DM digestibility. Studies conducted by Danley and Vetter (1973) with silages, Lippke (1980) with grass hays and Seone (1982) with legumes and grasses showed significant relationships between lignin or lignin:ADF ratio and DM digestibility. However, these relationships may be limited because of large forage species interactions (Van Soest, 1982).

Digestible energy of feeds is also affected by level of intake because of the interaction between digestion and passage rates (Nisa & Sarwar, 1998; Van Soest *et al.*, 1979). Moe *et al.* (1965) reported a reduction in total digestible nutrients from 3.4 to 6.2% per unit increase in feed intake equivalent to maintenance. Tyrrell and Moe (1974) stated that digestibility of cellulose and hemicellulose is depressed two to three times that of soluble carbohydrates at high intakes. Van Soest (1973) indicated that depressed digestibility with elevated intake is attributable to decreased digestibility of fibrous components and is almost entirely accounted for by altered cell wall digestibility.

Metabolizable Energy

Metabolizable energy is defined as the DE of a feed less urinary and gaseous energies (Blaxter & Clapperton, 1965). Losses of DE are about 5 to 12% for methane production and 3 to 5% in urine (Van Soest, 1982). Therefore, methane production may be considered as a loss of DE most affected by dietary fiber content. Blaxter and Clapperton (1965) demonstrated that methane production was higher for highly digestible diets than for less digestible diets at maintenance intakes. Increased level of high quality feed intake depressed methane production more compared with low quality feeds. Moe and Tyrrell (1979) reported that methane production was higher for feeds high in digestible cellulose than for those high in digestible soluble carbohydrates. However, methane production was not influenced as much by type of digested carbohydrate at low intake as at higher intakes. Thornton and Owens (1981) reported that energy losses from steers as methane for a low, medium and high fiber diets were 1740, 2052 and 2313 kcal per day (d), respectively. Unfortunately, statistical comparisons were not available because these diets were tested in independent trials. Moreover, the high fiber diet was offered at 4.1 kg DM/d while the medium and low fiber diets were fed at 5.4 kg DM/d. Johnson (1972) found that energy lost as methane from a 40% forage-containing diet fed at maintenance was 8% of the gross energy (GE) intake. Methane loss from the same diet at twice maintenance was 5.6%. Wedegaertner and Johnson (1983) reported that steers fed 70% cracked corn plus corn silage diet produced less methane as a percentage of GE as intake increased. Coppock (1985) indicated that reduction in gaseous and urinary energy appears to be the result of a higher percentage of concentration in diets at intakes of three to four times maintenance.

Utilization of Metabolizable Energy

The utilization of ME for a given purpose may vary according to the nature of the diet (Maynard *et al.*, 1979). Variation in the efficiency of utilization of ME results mainly from differences in the heat loss. There is some indication that fiber is associated with factors causing heat loss. Efficiency of utilization of individual nutrients has been reported by several authors (Maynard *et al.*, 1979; Van Soest, 1982; Garrett & Johnson, 1983). Blaxter and Clapperton (1965) concluded that heat increment above maintenance increased linearly with increasing molar proportion of acetate from ruminal fermentation. The relative molar proportion of ruminal volatile fatty acids (VFA) for different diet types indicates that forage diets lead to higher acetate production while concentrate diets stimulate a greater molar proportion of propionate (Sarwar *et al.*, 1991, 1992; Church, 1983). Estell and Galyean (1985) reported that molar proportion of acetate was correlated highly with ADF content of diets ($r = 0.84$; $P < 0.05$).

In general, there is agreement that varying mixtures of VFA are used with a similar efficiency for maintenance (Chalupa, 1984; McDonald *et al.*, 1985). However, controversy exists regarding the efficiency of use of VFA mixtures for fattening. Orskov *et al.* (1979), using intraruminal infusions of VFA mixtures, concluded that proportions of absorbed VFA did not affect efficiency of ME for fattening. Chalupa (1981) reported partial efficiency of utilization of acetate in varying mixtures of VFA for fattening ranged from 33 to 70% as compared with 56 to 84% for propionate and 62 to 86% for butyrate. Tyrrell *et al.* (1979) reported that use of ME from infused acetic acid for body tissue deposition was 27% for an all hay diet as compared to 69% for a 30% hay diet. It was concluded that partial efficiency of acetate for body tissue deposition depended on the type of diet.

Energy costs of eating, ruminating and work of digestion are associated with type of diet (Webster, 1978). Estimates of energy cost of eating for a hay, fresh forage and concentrate diet were 188, 146 and 104 calories per kg per minute, respectively. The cost of rumination may be approximately 40% of that of eating. Welch and Smith (1970) showed that rumination activity was correlated highly with cell wall intake (r=0.94). Woodford *et al.* (1986) reported that eating and ruminating times increased as NDF content of the diets increased from 21 to 30%. Osuji (1974) and Webster (1978) suggested that heat losses resulting from work of digestion of bulky forage might account for an appreciably high fraction of the total heat increment. In general, effects of fiber have been reflected in lower efficiency of use of ME. Garrett (1979) using diets varying in roughage level, reported that a linear relationship existed between percentage of roughage and efficiency of utilization of ME for maintenance (r=-0.97) or weight gain (r=-0.93). McGregor *et al.* (1983) reported that the ME of a diet with 32% NDF content was more efficiently used by dairy cows for the combined functions of maintenance and milk production (43%) than that of a diet with 37% NDF content (34%).

CONCLUSIONS

Digestible feed energy is generally influenced by the level of dietary fiber and its reduction is associated mainly with reduced fiber digestion. The digestion of high fibrous diets increases heat increment which generally results into reduced energetic efficiency for maintenance or production.

REFERENCES

Blaxter, K. L. and J. L. Clapperton, 1965. Prediction of the amount of methane produced by ruminants. *British J. Nutr.*, 19: 511-22.

Colenbrander, V. F., D. L. Hill, M. L. Eastridge and D. R. Mertens, 1986. Formulating dairy rations with neutral detergent fiber. 1. Effect of silage source. *J. Dairy Sci.*, 69: 2718-26.

Coppock, C. E., 1985. Energy nutrition and metabolism of the lactating dairy cow. *J. Dairy Sci.*, 68: 3403-10.

Church, D. C., 1983. *Digestive Physiology and Nutrition of Ruminants. Vol 1. Digestive Physiology.* 2nd Ed. O & B Books Inc., Corvallis, Oregon, U.S.A.

Danley, M. M. and R. L. Vetter, 1973. Changes in carbohydrate and nitrogen fractions and digestibility of forages: Maturity and Ensiling. *J. Anim. Sci.*, 37: 994-9.

Estell, R.E. and M.L. Galyean, 1985. Relationship of rumen fluid dilution rate to rumen fermentation and dietary characteristics of beef. *J. Anim. Sci.*, 60: 1061-8.

Fonnesbeck, P.V., J.L. Christiansen and L.E. Harris, 1981. Factors affecting digestibility of nutrients by sheep. *J. Anim. Sci.*, 52: 363-76.

Garcia, G.J., 1984. The effect of temperature and day length on rye grass and alfalfa quality. MS Thesis, Cornell University, Ithaca, NY., U.S.A.

Garrett, W.N., 1979. Relationships among diet, metabolizable energy utilization and net energy values of feedstuffs. *J. Anim. Sci.*, 49: 1403-9.

Garrett, W.N. and D.E. Johnson, 1983. Nutritional energetics of ruminants. *J. Anim. Sci.*, 57: 478-85.

Johnson, D.E., 1972. Effect of a hemiacetal of chloral hydrate and starch on methane production and energy balance of sheep fed a pelleted diet. *J. Anim. Sci.*, 35: 1064-70.

Jung, H.G. and K.P. Vogel, 1986. Influence of lignin on digestibility of forage cell wall material. *J. Anim. Sci.*, 62: 1703-9.

Lippke, H., 1980. Forage characteristics related to intake, digestibility and gain by ruminants. *J. Anim. Sci.*, 50: 952-60.

McGregor, C.A., M.R. Strokes, W.H. Hoover, *et al.*, 1983. Effect of dietary concentration of total nonstructural carbohydrate on energy and nitrogen metabolism and milk production of dairy cows. *J. Dairy Sci.*, 66: 39-50.

MAFF, 1976. *Energy allowances and feeding systems for ruminants.* Ministry of Agriculture, Fisheries and Food. Technical Bulletin No. 33. Her Majesty's Stationery Office, London, U.K.

Maynard, L.A., J.K. Loosli, H.F. Hintz and R.G. Warner, 1979. *Animal Nutrition.* 7th Ed., McGraw Hill Book Company, NY., U.S.A.

McDonald, P., R.A. Edwards and J.F.D. Greenhalgh, 1985. *Animal Nutrition.* 3rd Ed., The English Language Book Society and Longman Group Limited, London, U.K.

Mertens, D. R., 1983. Using neutral detergent fiber to formulate dairy rations and estimate the net energy content of forages. *Proc. Cornell Nutr. Conf.*, Ithaca, NY., U.S.A.

Mitchell, P.J., 1973. Relations between fiber and water soluble carbohydrate contents of pasture species and their digestibility and voluntary intake by sheep. *Australian J. Exp. Agric. Anim. Husb.*, 1: 65-70.

Moe, P.W., J.T. Reid and H.F. Tyrrell, 1965. Effect of level of intake on digestibility of dietary energy by high producing cows. *J. Dairy Sci.*, 48: 1053-9.

Moe, P.W. and H.F. Tyrrell, 1979. Methane production in dairy cows. *J. Dairy Sci.*, 62: 1582-90.

Nisa, M.U. and M. Sarwar, 1998. Effect of level of mottgrass intake and forage source on ruminal characteristics and nutrient digestibility in buffalo calves. *Indian J. Anim. Nutr.*, 15: 6-10.

Orskov, E.R., D.A. Grubb, J.S. Smith, A.J.F. Webster and W. Corrigall, 1979. Efficiency of utilization of volatile fatty acids for maintenance and energy retention by sheep. *British J. Nutr.*, 41: 541-8.

Osuji, P.O., 1974. The physiology of eating and the energy expenditure of the ruminants at pasture. *J. Range Manag.*, 27: 437-42.

Quigley, J.D., R. E. James and M. L. McGilliard, 1986. Dry matter intake in dairy heifers. 1. Factors affecting intake of heifers under intensive management. *J. Dairy Sci.*, 69: 2855-62.

Sarwar, M., J.L. Firkins and M.L. Eastridge, 1991. Effect of replacing neutral detergent fiber of forage with soyhulls and corn gluten feed for dairy heifers. *J. Dairy Sci.*, 74: 1006-17.

Sarwar, M., J.L. Firkins and M.L. Eastridge, 1992. Effect of varying concentrate level on nutrient digestibility and milk production of dairy cows. *J. Dairy Sci.*, 75: 1533-42.

Sarwar, M., M.A. Sial, W. Abbas, S. Mahmood and S.A. Bhatti, 1995. *In situ* ruminal digestion kinetics of forages and feed by products in Sahiwal cow male calves. *Indian J. Anim. Nutr.*, 12: 141-5.

Sarwar, M., S. Mahmood, W. Abbas and C.S. Ali, 1996. *In situ* ruminal degradation kinetics of forages and feed by products in male Nili-Ravi buffalo calves. *Asian-Australasian J. Anim. Sci.*, 9: 533-8.

Seoane, J.R., 1982. Relationships between the physio-chemical characteristics of hays and their nutritive value. *J. Anim. Sci.*, 55: 422-31.

Chalupa, W., 1984. Manipulation of rumen fermentation. *In:* W. Haresign and D. J. A. Cole. (Ed.). *Recent Advances in Animal Nutrition.* pp. 143-60. Butterworths, London, U.K.

Thornton, J.H. and F.N. Owens, 1981. Monensin supplementation and *in vivo* methane production by steers. *J. Anim. Sci.*, 52: 628-34.

Tyrrell, H.F., P.J. Reynolds and P. W. Moe, 1979. Effect of diet on partial efficiency of acetate use for body tissue synthesis by mature cattle. *J. Dairy Sci.*, 48: 598-605.

Tyrrell, H.F. and P.W. Moe, 1974. Effect of intake on digestive efficiency. *J. Dairy Sci.*, 58: 1151-9.

Van Soest, P.J., 1965. Voluntary intake in relation to chemical composition and digestibility. *J. Dairy Sci.*, 24: 834-41.

Van Soest, P.J., 1973. Revised estimates of the net energy values of feeds. *Proc. Cornell Nutr. Conf.*, Ithaca, NY., U.S.A.

Van Soest, P.J., 1978. Evaluation of forages and feedstuffs in the laboratory. *Proc. 6th Int. Vet. Cong.*, Buenos Aires, Argentina.

Van Soest, P.J., 1980. Fiber quality in dairy rations. *12th Biennial Ruminant Health Nutrition Program,* New York State Veterinary College, Ithaca, NY., U.S.A.

Van Soest, P.J., 1982. *Nutritional Ecology of the ruminant.* O & B Books, Inc., Corvallis, Oregon, U.S.A.

Van Soest, P.J., J. Fadel and C.J. Sniffen, 1979. Discount factors for energy and protein in ruminants. *Proc. Cornell Nutr. Conf.*, Ithaca, NY., U.S.A.

Van Soest, P.J. and D.R. Mertens, 1977. Analytical parameters as guides to forage quality. *Proc. Int. Meet. Anim. Prod.* from temperate grassland, Dublin, Ireland, U.K.

Van Soest, P.J. and J.B. Robertson, 1979. Systems of analysis for evaluating fibrous feeds. *In*: W.J. Pgden, C.C. Balch and M. Graham. (Eds.). *Procedures of Standardization of Analytical Methodology for Feeds.* IDRC Ottawa, Canada.

Webster, A.J.F., 1978. Prediction of the energy requirements for growth in beef cattle. *Wrld Rev. Nutr. Diet,* 30: 189-96.

Wedegaertner, T.C. and D.E. Johnson, 1983. Monensin effects on digestibility, methanogenesis and heat increment of cracked corn-silage diet fed to steers. *J. Anim. Sci.*, 57: 168-77.

Welch, J. G. and A. M. Smith, 1970. Forage quality and rumination time in cattle. *J. Dairy Sci.*, 53: 797-806.

Woodford, J. A., N. A. Jorgensen and G. P. Barrington, 1986. Impact of dietary fiber and physical form on performance of lactating dairy cows. *J. Dairy Sci.*, 69: 1035-43.

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