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in

Brufau J. (ed.), Tacon A. (ed.).
Feed manufacturing in the Mediterranean region: Recent advances in research and technology

Zaragoza : CIHEAM
Cahiers Options Méditerranéennes; n. 37

1999
pages 249-257

To cite this article / Pour citer cet article

Succi G., Crovetto G.M. **Nutritional strategies in ruminant feeding.** In : Brufau J. (ed.), Tacon A. (ed.). *Feed manufacturing in the Mediterranean region: Recent advances in research and technology.* Zaragoza : CIHEAM, 1999. p. 249-257 (Cahiers Options Méditerranéennes; n. 37)

Nutritional strategies in ruminant feeding

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SUMMARY - The main mechanisms involved in N excretion and CH_4 emission by ruminants are briefly summarized. While the contribution of ruminants to the global warming effect through CH_4 emission seems to be exaggerated, this is not the case for N pollution: there is an urgent need for a reduction of N excretion into the environment and animal nutritionists and farmers must be aware of this. Diets fed to dairy cows or beef cattle should contain the minimum N content, but all the fermentable energy needed to maximize rumen microbial protein synthesis. Additional single rumen protected amino acids can be satisfactorily included in low protein diets to meet metabolic amino acid requirements. Forages (preferably of medium N and high energy content) and other home-grown feedstuffs are increasingly used on cattle farms. In Italy, diets for dairy and beef cattle in the most intensive areas are mainly based on maize silage as the principal forage component and maize grain (dry or wet) as the energy concentrate supplement. The quantitative and qualitative differences between maize silage as the first, and only crop in the year and maize silage as a second crop after Italian ryegrass or a winter cereal, are discussed. The results of some studies on dietary N reduction in lactating cows and some typical diets fed in Northern Italy are also reported and commented upon.

Key words: Ruminant nutrition, nitrogen, methane, environment.

RESUME *- "Stratégies alimentaires chez les ruminants". Cet article présente les plus importants mécanismes impliqués dans l'excrétion d'azote et dans l'émission de méthane chez les ruminants. Tandis que la contribution de l'émission de méthane semble être négligeable pour l'échauffement de l'atmosphère, il devient de plus en plus urgent de réduire les quantités d'N excrétées et, par conséquent, de réduire la pollution environnementale. Des solutions alimentaires existent pour limiter et réduire dans certains cas les rejets azotés : par exemple les rations des bovins à lait ou à viande doivent apporter le minimum d'N mais l'énergie fermentescible nécessaire pour maximiser la synthèse des protéines microbiennes. L'addition d'acides aminés protégés à des rations limitées en N peut contribuer à couvrir les besoins des ruminants. L'utilisation de fourrages très ingestibles, très digestibles et très énergétiques devient un atout essentiel pour alimenter au mieux les animaux. En Italie les rations pour les bovins, dans les conditions d'intensification fourragère, sont fondées surtout sur le maïs fourrage (ensilage de la plante entière, des épis complets ou des grains humides). On présente et on commente certains régimes alimentaires typiques dans les élevages de la plaine du Pô.*

Mots-clés : *Ruminants, nutrition, azote, méthane, environnement.*

Introduction

It has long been considered by the public that ruminants, in contrast to monogastric animals, had little or no impact on the environment. In fact, in comparison with monogastric farm animals, the more extensive farming conditions, the lower energy and protein requirements to ensure a satisfactory level of production, nitrogen recycling in the animal, diets based primarily upon forages produced directly in the farming areas, the more diluted slurry and its lower BOD, all contributed to inducing a belief that ruminant farm animals should not have any detrimental effect on the environment.

However, the increasing attention paid to the environment and the primary need to preserve it from degradation for the future on one hand and the more and more intensive meat and milk production pursued by farmers in many European countries on the other, have led to an alarming situation not only concerning pig production units, but also from numerous beef and dairy operations. Moreover, the need to reduce the costs of production has led to a concentration of the farms with an increasing number of animals per farm.

Feeding strategies are clearly related to the excretion of waste in animal production and influence it both quantitatively in terms of carbon dioxide (CO_2), methane (CH_4), faeces and urine and qualitatively, in terms of the faeces/urine ratio, moisture and phosphorus (P) content of faeces, nitrogen (N) content of the urine, feed additive residues, etc.

In ruminants there are several products of metabolism which could have an impact on the environment; as it is not possible to consider all of them, we will focus our attention to two products, CH_4 and N which -rightly or not- are considered the most dangerous, at least potentially.

Methane emission and warming effect

It is well known that the concentration of greenhouse gases in the atmosphere, particularly CO_2 and CH_4, has increased greatly in recent decades with a consequent warming of the earth's surface. Atmospheric CH_4 increased by more than 1% per year between 1980 and 1990 (Rodhe, 1990), while information on long-term trends in CH_4 levels has been obtained from the analysis of air bubbles trapped in the ice sheets of Greenland and Antarctica (Bolle *et al.*, 1986, cited by Moss, 1993). The data obtained show an exponential increase of the tropospheric CH_4 during the last three centuries, well correlated with the increase in the human world population and, consequently, with human activities among which agriculture certainly plays a role.

The concentration of methane in the atmosphere is much lower (1.7 ppm) than CO_2 (350 ppm) and it has a much shorter atmospheric half life. However, these factors are more than offset by the higher intensity of infrared energy absorption per gram of CH_4 in comparison with CO_2. Globally, CH_4 is believed to cause about 15% of the overall warming as compared to 55% from CO_2 (Johnson *et al.*, 1991).

Despite the fact that a lactating cow produces annually almost as much CO_2 as a car, the essential difference between traffic and cattle is that the CO_2 produced by cattle derives entirely from newly generated biomass and therefore does not contribute to a net increase of CO_2 in the atmosphere, while cars burn fossil fuel (Tamminga, 1996).

As far as CH_4 is concerned, major contributors to global CH_4 emission into the atmosphere are: (i) natural wetlands (21%); (ii) rice fields (20%); (iii) losses during energy production from fossil fuel (14%); (iv) domesticated animals (14%); burning biomass (10%); and (v) landfills (7%) (Johnson *et al.*, 1991). Ruminants, and particularly cattle, contribute most heavily (>70%) to the total CH_4 emission from animals. Therefore, domestic cattle contribute approximately only 1.5% of the global warming effect (15% of warming from CH_4 x 14% of CH_4 from livestock x 72% of global animal CH_4 emission from cattle; Johnson *et al.*, 1991). This means that, even if it were possible to reduce the world cattle CH_4 emission by 50% (difficult to imagine!), there would only be a final advantage of 0.7% in terms of global warming reduction.

However, examining the problem from a production efficiency viewpoint, CH_4 emission by ruminants represents a non-negligible loss of dietary energy. In fact, energy lost as CH_4 represents 5-9% of the gross energy (GE) in ruminant diets. CH_4 is one of the end-products of anaerobic microbial fermentations in the rumen. More precisely, the majority of CH_4 in the rumen is produced by the reduction of CO_2; many carbohydrate-fermenting bacteria and protozoa produce formate (via the acetic fermentation pathway), hydrogen (H) and CO_2 as fermentation products. H, in turn, can be removed either by the formation of reduced fermentation products (lactate, ethanol), or by the formation of H gas; the latter thus becomes one of the main substrates for rumen methanogenesis. It should be considered that the inhibition of methanogenic bacteria cannot be achieved as a single event: the whole pattern of rumen fermentations would be influenced by factors aimed at reducing methanogenesis.

For decades, much research all over the world has aimed at reducing CH_4 emission and hence to improve the efficiency of GE utilization. A well documented inverse correlation exists between CH_4 and propionic acid production in the rumen. It has long being known that diets rich in readily fermentable carbohydrates (sugars and starch) enhance propionate fermentation at the expense of acetic with a consequent reduction in CH_4 production.

Some feed additives, such as the ionophores, reduce CH_4 production after their inclusion in the diet, but the effect disappears after a few weeks (Johnson *et al.*, 1991).

The physical form of feed (particularly roughages) is another factor which influences the extent of methanogenesis: a whole pelleted diet tends to reduce CH_4 production.

Among the feeding factors able to reduce CH_4 emission by ruminants, particularly cattle, fat-rich feeds have a certain interest, presumably more for their high net energy content than for their ability to reduce methanogenesis. Indeed, most lipids negatively interfere with fibre digestion processes in the rumen and consequently reduce methanogenesis. There are substantial differences between different dietary fat sources: in an experiment conducted by Machmüller *et al.* (1997) coconut oil proved to be efficient in reducing protozoa count and CH_4 yield in the rumen without negative effects on digestibility and the utilization of dietary energy; other fatty feeds (rapeseed, sunflower seed, linseed) depressed methanogenesis, but energy digestibility, metabolizability and metabolizable energy utilization as well; rumen inert fat was digested and metabolized efficiently, but with no effect on methanogenesis.

In general, it can be observed that CH_4 production is enhanced by feeds with a high digestible fibre content which favours cellulolytic bacteria and acetic fermentation. On the other hand, however, such fibrous feeds are normally farm-produced and less expensive than starchy, low-fibre feeds. Moreover, considering the environmental implications from a wider point of view, we must consider that the necessary input of fossil energy is lower for forages (1-3 MJ/kg DM) than for concentrates (7-15 MJ/kg DM); this means that a diet with a high forage proportion reduces the input of fossil energy directly related to the feed (Tamminga, 1996).

Ruminants are primarily reared for their capacity of utilizing fibrous feeds, which are almost completely undigestible by monogastrics. In conclusion, in the formulation of diets for ruminants, it seems advisable to make a balance between cheap, home-grown, fibrous feeds and more energetic, starchy feeds, able to boost milk and meat productions.

The environmental impact of nitrogen

If the contribution of ruminants to environmental pollution through CH_4 emission is perhaps more an impression than a real problem, this is not the case for N. Ammonia in the air and, in particular, nitrates (NO_3) in soil and ground water represent major negative factors in environmental impact. Fertilizers (particularly NO_3 and ammonium salts) and manure are the main N sources in this respect. In contrast to P (excreted mainly with faeces), N is excreted by the animal mainly in the urine, as urea. The latter is rapidly converted into ammonia which in turn is converted to NO_3 by nitrification in aerobic conditions (e.g., in the upper part of the soil). In contrast, in the lower parts of soil, anaerobic conditions make denitrification possible ($NO_3 \rightarrow N_2$) with intermediate gases such as NO, N_2O and NO_2 escaping into the air. N_2O, in particular, is harmful to the ozone layer. The nitrates which escape denitrification leak into the ground water which becomes less suitable for drinkable water.

In many European countries, the intensification of farming systems over recent decades has increased N input/kg N excreted in milk two- or three-fold; this intensification has been attained in two ways: (i) by growing more feed on the farm with higher N fertilization; and (ii) by buying more concentrates produced elsewhere. In a study by Korevaar (1992) in The Netherlands, N and P surplus per hectare approximately doubled from 1950 (376 and 24 kg, respectively) to 1985 (650 and 54 kg) increasing the milk yield from 8.7 to 20.5 ton/ha. However, when expressed on a per kg milk basis, surplus N decreased by 25% whereas surplus P remained constant.

Increased N fertilization allows a constant milk production per cow and per hectare to be maintained by increasing the proportion of home-grown forages in the diet and lowering the supply of concentrates. As a result there is an enhanced surplus of N and P per hectare and per kg of milk. However, as previously stated, this means of intensification reduces the input of fossil energy directly related to the feed as there is a lower input of fossil energy to forages than concentrates.

The N level in diets fed to ruminants, particularly dairy cattle, has slowly but constantly increased over recent decades in order to fulfil the requirements for amino acids associated with increasing growth rate and milk yield. The same occurred with energy: passing from 20 to 30 or 40 kg milk/day, i.e., from 6 to 9 or 12 tons of milk/year per cow, a ration based mostly on hay as the primary forage component (5.0 MJ NE_l equivalent to 0.70 UFL/kg DM on average, in Italian climatic conditions) to meet the high energy requirements (0.90-0.97 UFL/kg DM) will necessarily include a very high proportion of concentrates, with a consequent risk of metabolic disorders.

Nitrogen is excreted mainly with faeces and urine. Faecal N depends on the N content of the diet and its digestibility; it includes undigested nitrogenous fractions and endogenous nitrogenous substances. With increasing quantities of DM passing through the intestinal tract, endogenous N losses are likely to increase as well. However, provided that DM and its OM component are potentially well digestible (as it is the case with early cut forages and low lignin content concentrates), endogenous N losses should not increase sufficiently to represent a risk for environmental pollution.

Most of problems linked to N, however, come from the urine rather than from faeces. Maintenance losses of N decrease proportionally with increasing levels of production. Any increase in the production level leads to an increase in N intake and the N excreted with urine, but results in a proportional decrease in total N excretion per ton of milk produced (Table 1). This should warn against simplistic and fashionable solutions such as extensification of animal production systems; they can be useful and conveniently adopted in some cases, but certainly not always or everywhere and a careful economic/social study of the different options must be made.

Table 1. Effect of the level of production on N flow per year. Diets with maize silage throughout the year, 8.2% CP in DM (Delaby *et al.*, 1995)

N flow/year	Kg/cow			Kg/ton milk		
Milk (kg/year)	6000	7500	9000	6000	7500	9000
N Ingested	112	131	149	18.5	17.5	16.5
N with concentrate (% of N ingested)	45	50	55			
N excreted with milk and calf	32	40	48	5.3	5.3	5.3
N excreted with faeces	37	42	46	6.2	5.6	5.1
N excreted with the urine	43	49	55	7.2	6.5	6.1

Some 10% of the ingested N is lost as microbial nucleic acids and this loss is almost unavoidable. Another part (10-15%) of the dietary N is lost after amino acid absorption, due to gluconeogenesis, the unbalanced composition of the amino acid pool available for the mammary gland and the limited capacity of the mammary gland itself to synthesize casein. Moreover, a diet with a high N content will induce high N excretion with urine and -in some cases- also health (udder, feet, intestine) and reproductive problems. Feeding excess protein, even if from a high quality source, will not raise quantitative and qualitative production levels; on the contrary, a high level of absorbed protein (AP) for a given net energy (NE) intake, will decrease the efficiency of AP utilization by the dairy cow (Tamminga, 1992).

On the basis of the above reasoning, the advantage of using a modern protein evaluation system in which the supply of absorbed amino acids is related to the supply of NE should be apparent. Models to compare efficiencies of N utilization and balances of inputs and outputs with different management strategies have already been proposed (among others: Dou *et al.*, 1996).

The best results seem to be achieved by diets low in protein but with high quality OM and a high non-structural carbohydrate (NSC) content in order to supply the animal with all the NE needed per unit time to sustain high levels of production.

Protein and energy nutrition on Italian intensive dairy farms

As generalization can sometimes lead to incorrect statements, we prefer to restrict our considerations to Italy. In Italy, almost 80% of milk is produced in highly intensive farming areas, mostly irrigated and particularly suitable for maize production. High summer temperatures accelerate forage lignification processes, whereas the rainy conditions during the first and last cuts make it difficult to obtain a good hay (both grass and lucerne) without severe nutritional losses in the field and later on during storage. As a result, the hay obtained is often of low nutritional value. Conservation of forages by ensiling rather than drying allows a reduction in DM and nutritional losses with significant advantages in terms of less NDF and ADF and higher NE contents: DM and energy intake will increase as will degradability, rumen turnover, digestibility and energy utilization, with positive effects on milk or meat production.

Protein and amino acid requirements of dairy (and beef) ruminants can be met: (i) with diets with a relatively low protein content but with a highly degradable fraction enhancing microbial protein synthesis; and (ii) from diets with a high protein content and a relevant proportion of dietary undegradable ("by pass") protein. In the decade 1985-95 in Italy it was quite popular to formulate diets for lactating cows which were fairly high in total and by pass (mostly animal) protein. In contrast, economic and health reasons have favoured a recent tendency to lower the dietary protein content at the expense of the undegradable fraction. Where possible, forage and, in general, home-grown feeds are used by dairy and beef farmers, to cut feed costs which have now dropped from over 60 to 50% of the total cost of milk production. In recent years, the feed compounding industry has lost a large volume of sales in the dairy and beef sectors: more and more farmers buy protein, vitamin and mineral supplements (4-6 kg/cow daily) rather than the traditional compound feedstuffs (10-12 kg/cow); they prefer to produce the maize directly (dry grain, wet grain or ear) and in most cases purchase other feeds (soyabean meal, whole cottonseeds, dried beet pulp, roasted soyabean seeds, molasses, etc.) themselves. The mixer wagon really has become a feed industry in miniature and integrated farming systems (where agronomic rotations and crop planning are carefully studied to be as self-sufficient as possible) have been developing rapidly.

In most diets used on beef and dairy cattle farms, maize silage represents the main forage. It can be produced either as the first (and sole) crop in the year or as a second crop, after harvesting and ensiling a winter cereal forage (rye, wheat, barley, triticale, oats) or most frequently Italian ryegrass. In the past, the latter used to be dried in the field to produce a hay which often had a low nutritive value because of field losses related to adverse weather conditions; in recent years, Italian ryegrass (as well as most of the first and last cut of permanent pastures and seeded meadows) is conserved as silage after 1-3 days of wilting (to about 30% DM if a silage clamp is used, 40-50% DM in the case of wrapped big round bales or vertical silos). In comparison with Italian ryegrass, winter cereal forages have the advantage of a higher DM content at the cut (normally 30% at the milk stage of maturity) which enables direct chopping and ensiling without wilting. This reduces the risk of losses due to rain and soil-clostridia contamination.

The maize hybrid to be chosen and the quantitative and qualitative maize silage production depends greatly on the time of seeding which in turn depends on the preceding crop. When rye is sown in autumn, the forage can be cut, chopped and ensiled at the beginning of April, at the stage of heading. In this case, a maize hybrid of class FAO 700 (135 days) can easily be sown. After a crop of Italian ryegrass (cut at the first week of May, at the stage of heading, beginning flowering) a class 600 maize can be employed. After winter cereals (wheat, triticale, barley, oats) harvested at the milk stage of maturity (about the end of May), class 500 maize should be used. If the maize silage has to follow a harvest of barley grain (late June), class 400 must be chosen. The most common situation in Northern Italy is to sow maize for maize silage production as a first crop or as a second crop after Italian ryegrass. Normally there is a significant difference between 1st and 2nd crop maize silage both in terms of DM yield and quality: first crop maize silage normally has a higher DM yield (21-25 *vs* 15-18 ton/ha) and DM content (35 *vs* 30%), a higher starch (30-36 *vs* 25-28% DM) and NE_l (6.40 *vs* 6.00 MJ/kg DM) concentration and a lower NDF content (40-47 *vs* 45-53%).

Table 2 shows the composition and some analytical parameters of nine total mixed rations (TMR) fed to lactating cows on 9 farms in the Lombardy Region throughout 1996. As can be seen, most of the diets reported have a high NE concentration, but a fairly low protein content. Degradable protein was around 60% and soluble protein around 30% of crude protein.

The total NDF content is somewhat higher than the corresponding (in terms of level of production) diets of Northern Europe and North America; however, DM intake is satisfactory and sufficient to maintain the level of production. NSC concentration is in the range of 36-42% DM and is the key to reaching a high NE content.

Table 2. Composition and main analytical parameters of some total mixed rations fed during 1996 on nine dairy farms of the provinces of Milan (1-4), Mantova (5, 6, 9), Cremona (7) and Como (8). CP: crude protein; DIP: (rumen) degradable protein intake; SIP: (rumen) soluble protein intake. NSC, DIP, SIP, NE_l, Met and Lys and the predicted milk urea were computed with the Cornell Net Carbohydrate and Protein System (CNCPS, 1994).

Farm No.	1	2	3	4	5	6	7	8	9
Milk yield (kg/d)	35	34	35	33	33	32	33	32	30
Maize silage	19	20	18	18	21.5	17	20	28	-
Italian ryegrass silage	9.5	10	4	11	-	-	-	-	-
Oat silage	-	-	-	-	-	-	1.5	-	-
Lucerne hay	-	-	-	-	3	3	1.8	-	11
Lucerne silage	-	-	3	-	4.7	6	3.6	-	-
Permanent pasture hay	-	1	3	-	-	1	-	5	-
High moisture corn	6.6	-	-	-	-	-	-	-	-
High moisture ear corn	-	-	4	10	6	-	4	-	-
Maize meal	-	4	3	0.8	1.7	6	3.3	2.7	6
Barley meal	-	-	-	-	-	-	-	1.5	2
Soyabean meal	3.38	-	2.4	1.9	1.4	2	3.1	1.9	1.8
Whole soyabean seeds, roasted				0.7	1	-	1.5	-	1
Whole cotton seeds	3	-	1	2	-	-	-	2	-
Corn gluten feed	-	2.5	-	1	1.5	-	-	-	-
Distillers	-	2	-	0.5	-	-	-	1	-
Linseed expeller	-	1.5	1	1.3	-	-	-	1	-
Maize germ expeller	-	-	0.7	-	-	-	-	-	-
Coconut expeller	-	-	0.4	-	-	-	-	-	-
Herring meal	0.3	0.3	-	0.2	0.5	0.6	-	0.3	-
Beet pulp, dried				1	-	1	1.2	-	2.5
Sugarcane molasses	2	-	-	0.2	-	-	-	-	-
Rumen inert fat	-	-	0.2	-	0.3	0.3	-	-	-
Urea	0.08	-	-	-	-	-	-	-	-
Vit./min. supplement	0.8	0.5	0.5	0.5	0.5	0.4	0.6	0.4	0.3
DMI (kg/d)	21.9	21.3	23.0	22.0	21.3	21.5	20.5	22.3	22.0
CP (% DM)	17.5	16.9	16.3	16.5	16.6	16.3	17.2	15.0	17.3
DIP (% CP)	69	58	60	63	61	61	62	62	57
SIP (% CP)	37	28	27	29	31	29	25	27	20
NDF (% DM)	28	37	37	36	35	33	32	36	36
NSC (% DM)	42	37	36	38	38	41	42	40	41
NE_l (MJ/kg DM)	7.32	7.11	6.97	7.32	7.15	6.98	7.20	6.90	6.32
UFL/kg DM†	1.03	1.00	0.98	1.03	1.00	0.98	1.01	0.97	0.89
MET and LYS (% requirement)	115	114	107	119	123	132	113	111	121
Milk urea (mg/100 mL)	28	30	30	26	28	28	28	24	37

†UFL: milk fodder units in the French system, where 1 UFL=7.113 MJ NE_l

Maize silage, in this context, plays an essential role: its extremely high DM yield, the low protein and NDF contents associated with the high starch and NE_l concentrations, make it the ideal forage to lower feed costs, enhance milk yield and milk protein and reduce N excretion and CH_4 emission.

Diet 9 in Table 2 is the only ration with no maize silage and it has the lowest NE content and the highest milk urea (MU) concentration. The crude protein content of diet 9 was similar to those of diets 1 and 7 and its protein degradability and solubility even lower; however, the high NE concentration of diets 1 and 7 led to a reduction in MU, which was not the case for diet 9. For the latter, a lower crude protein content would have been preferable both for production performance and the environmental impact of N.

The amino acid balance, metabolic lysine and methionine requirements should be supplied at 110% of the requirement, as suggested by the Cornell Net Carbohydrate and Protein System (CNCPS, 1994). Diet 3 and, to a lesser extent, diet 8 are the border line in this respect. Interestingly, most of the diets met the amino acid requirements despite the moderate crude protein content; this was achieved with the high fermentable energy levels included in the rations, which promote microbial protein synthesis and hence digestible amino acid supply to the intestine.

Some nutritionists in Italy are more drastic and balance dairy rations for high yielding cows (>35 kg milk/d) to get a CP content of 15-16% on a DM basis, with some 65-70% rumen degradable N and half of it being soluble N (see diet 1 in Table 1). This low N concentration is combined with a high NSC content: 40-44% DM, with 30-34% starch on a DM basis. Most of the starch comes from maize which can be supplied wet (either as high moisture corn, HMC, or high moisture ear corn, HMEC) or dry. In the latter case, the kernels are normally finely milled (2-4 mm) with the aim of improving rumen degradation rate, which is normally quite low for maize starch, particularly when dry. The overall aim is to match and synchronize the availability of N and energy in the rumen and increase the degradation rate of OM in order to maximize rumen turnover, the rate of passage of digesta through the gastro-intestinal tract and consequently DM intake. The inclusion of buffers ($NaHCO_3$, $CaCO_3$, MgO, bentonite, etc.) to the diet, particularly in the case of silage-based diets, is highly advisable to maintain rumen pH above a safety margin.

In fact, the maximization of feed intake is the key factor to attain higher levels of production and at least partially meet the extremely high energy and protein requirements of the animal. However, from both a production and environmental point of view, quantities rather than concentrations need to be considered: cows and beef cattle consume grams of protein and MJ of NE, not percentages! A daily individual ingestion of 25 kg DM from a diet with 15% CP on a DM basis will give a higher N intake than a 17% CP diet ingested at a level of 21 kg/d.

Dietary protein content and amino acid supplementation

The dietary supply of protein can be reduced provided that this leads to a lower excretion of N which is not at the expense of animal performance. Satisfactory milk (and hopefully meat) production can also be attained with a lower protein content of the diet provided that the essential amino acid and overall N (for the synthesis of the non-essential AA) requirements are met. Last, but not least, a diet characterized by a relatively low N content will induce less stress and subclinical diseases in the animal.

A study of the effect of the dietary protein content and the addition of rumen protected lysine and methionine on N utilization by lactating cows was conducted in France by Robert *et al.* (1995): the main results are summarized in Table 3. The data obtained indicate that a significant reduction in N excretion (mainly as urinary N) can be obtained by diminishing the crude protein level of the diet.

In another Latin square trial conducted by our Institute with 92 lactating cows, rumen protected methionine and lysine were added to diets with normal (17% DM basis) and reduced (15%) crude protein content to study the effect on milk production. The two amino acids were added in quantities to reach the levels suggested by Rulquin *et al.* (1993): 7.3% and 2.5% of the intestinal digestible protein for lysine and methionine, respectively. The main results of the experiment are reported in Table 4.

Low protein diets depressed slightly, but not significantly, feed intake and milk yield. The milk protein content was significantly increased by the inclusion of the amino acids in the diets. The proportion of casein N remained constant, while a significant reduction of milk urea content was recorded for the low protein diets, independently of the amino acid addition. The possibility of maintaining a low (<19 mg MUN/dL, corresponding to 41 g MU/dL) MU concentration is important to avoid a fall in the pregnancy rate (Butler *et al.*, 1996). Overall, the low protein diet with added rumen protected lysine and methionine gave similar production performance and a significantly lower milk urea content compared to the control diet with a higher CP content. Moreover, it is easy to predict, after the previously cited study, that N excretion by the cows fed the low protein diets must have been considerably lower than that of the same cows fed the high protein rations.

Table 3. Effect of the protein content of the diet and of the addition of rumen protected lysine and methionine (AA) on N utilization by lactating cows (Robert *et al.*, 1995)

CP content (% DM)	15	15	17	17	SEM	Significance
AA addition	0	+	0	+		
N ingested (I) (g/d)	401	428	450	465	13	NA
N in faeces (F) (g/d)	105	101	100	109	16	
N in urine (U)(g/d)	109	72	131	155	22	N
(I-F-U)/I (%)	46	59	48	43	6	Na
(I-F-U)/(I-F) (%)	63	78	62	56	7	Na

N: effect of the protein content of the diet; A: effect of the AA supplementation
Capital letters: P≤0.01; small letters: P≤0.05

Table 4. Effect of the addition of rumen protected lysine and methionine (AA) to diets with high or low protein content, on milk production by cows (Succi *et al.*, 1997)

CP content (% DM)	15	15	17	17	SEM	Significance		
AA addition	0	+	0	+		15 *vs* 15+	17 *vs* 17+	17 *vs* 15+
Ingestion (% fed)	95.1	96.2	97.8	99.7	0.66	NS	NS	NS
Milk yield (kg/d)	30.8	31.3	31.9	32.1	0.24	NS	NS	NS
Milk fat (%)	3.41	3.39	3.47	3.35	0.03	NS	*	NS
Milk protein (%)	3.15	3.19	3.18	3.24	0.01	***	***	NS
Casein N (% tot N)	74.6	75.3	73.2	73.5	0.32	NS	NS	NS
Milk urea (mg/dL)	28.5	29.0	40.0	39.3	0.07	NS	NS	***

*P≤0.05; ***P≤0.001; NS: Non significant

Conclusions

High yielding cows or beef cattle must be fed diets containing high energy densities and the necessary quantities of protein and amino acids. This does not necessarily mean increasing environmental pollution. In fact, despite the higher input of fossil energy associated with better quality feeds, increasing production per animal generally reduces the input of energy from biomass per kg of product. Ruminant feeding strategies should aim at: (i) utilizing home-grown feeds, particularly forages; (ii) keeping the dietary N content fairly low; and (iii) maintaining a high readily fermentable energy supply to sustain microbial growth and animal performance. Amino acid supplementation can improve protein balance and allow the requirements of high production animals to be satisfied even with a moderate protein content diet.

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