Session 12 - Nutrition of the High Yielding Cow

Diet-health relationship in the transition period: consequences on energy balance and efficiency

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Summary – This paper deals the feeding of high yielding dairy cow which cannot satisfy actual need, except very short periods of its life. However, a moderate shortage of energy in early lactation and a proper recovery afterwards is typical of many species; very important is obviously the way to manage it. The most critical period is of course the transition period, but a simple increase of energy content at the end of pregnancy and very early lactation is not always effective; quite often the situation is not modified and many times it is worsened. Apparently the "key" is to maintain dry matter intake at good level till calving and then to ensure its quick rise in the first month of lactation. To obtain this, the health conditions are of paramount importance (not only clinical, but also subclinical diseases), because pro-inflammatory cytokines can impair the energy balance in a double manner: reduction of dry matter intake and worsening of energy efficiency. To conclude, not only feeding ("low" energy before calving and "high-safe" energy in lactation), but any tool to avoid diseases, tissue damages, stresses etc., must be realized in the transition period.

Key words – dairy cows, dry matter intake, inflammations, cytokines, energy efficiency

Introduction

Diet is in general evaluated according to the composition of its feeds which affect both rumen fermentation and protein synthesis rate, as well as rumination activity; the latter being mainly influenced by total crude fiber content and its physical efficacy. All these phenomena are in fact responsible of over all energy-protein supply and of proper gastro-intestinal tract functions. Nevertheless, because nutrient intake is also function of Dry Matter Intake (DMI), precise and accurate prediction of DMI is important to prepare balanced rations also in case of farms with difficulty to properly estimate feed intake (Hayirli et al., 2003). In fact, for a quantitative approach, besides digestibility and its affecting factors (crude fiber, rumen flow rate etc.), the DMI is of major importance, particularly because it is not affected by feed traits only (Forbes, 1983). The main dietary factors that affect feed intake are the filling effect of diets, the rumen fermentability of diets, type and amount of fat in the diet, and nutrients that limit maximum milk yield (Allen, 2001). Nevertheless, animal factors are of major importance: milk yield (MY), metabolic body weight, fat deposition, age, physiological status, energy requirements etc., because they affect appetite and gastro-intestinal volume, particularly in the transition period. However, if whole lactation is considered, the relationship between MY and DMI is not always perfect; in fact, DMI grows slowly in early lactation and it decreases also slowly at the end of lactation. Hristov et al. (2002) suggest a R^2 value of 0.47, but what is important to understand is whether MY is driven by DMI changes – as suggested by Mertens (1996) and by Martin and Sauvant (2002) – or viceversa is MY the main "driver" of DMI, as we have showed (Calamari et al., 1991) but particularly after 60 DIM (Days In Milk).

Our unpublished results tend to confirm that the lag between peak MY and peak DMI in the early stages of lactation, suggests the concept that intake is driven by milk production (NRC, 2001). It can be supposed that high MY and consequent NEB (Negative Energy Balance), forces some morpho-physiological changes: a higher dimension of gastro-intestinal tract, but also higher absorption capacity (Vernon, 1989). Obviously the effects of MY are accompanied by many other factors, also affecting

DMI; for instance, the prediction of MY is improved if net energy intake, respect to DMI, is utilized (Hristov et al., 2005); maybe because NDF, physically effective NDF, but also fermentable starch can have contradictory effects on DMI and MY (Hristov et al., 2002). It is in fact reasonable that high fiber, particularly the effective one, can reduce the DMI (and MY in some extent), but the opposite situation, with excess of fermentable materials, despite more digestible, can induce a lower pH (acidosis) and in turn, low rumen pH, may decrease DMI (Allen, 1997).

Nevertheless, talking of transition period, the higher nutrient requirements due to the quick raise of milk yield tends to increase DMI (Forbes, 1983), but the relatively small size of digestive apparatus – after dry period - has a opposite effect (physical limit). Therefore, distension in the rumen is a important factor affecting DMI of high producing cows and it becomes a more dominant mechanism regulating feed intake as milk yield increases (Allen, 2001). However, in the first part of lactation, MY and DMI are largely independent and this is the main cause of a NEB (Figure 1). In fact, it is important to show that NEB degree is not correlated with MY, but with DMI (Drackley, 2006); similar results have been obtained long time ago, but rarely cited. Thus, Villa-Godoy et al. (1988) showed clearly that the variations in NEB were explained largely by intake of energy (appetite) and to a lesser extent by MY (lower DMI than expected did justify the worse NEB). Similarly, Staples et al. (1990) have showed that anoestrus cows ate less feed, produced less milk and lost more body weight, resulting in a more negative energy status that cycling cows (both groups were of similar genetic merit and were receiving the same standardized husbandry). In other words, high yielding cows could have a better energy balance, respect to lower yielder, if their DMI grows quickly and becomes higher as usually expected.

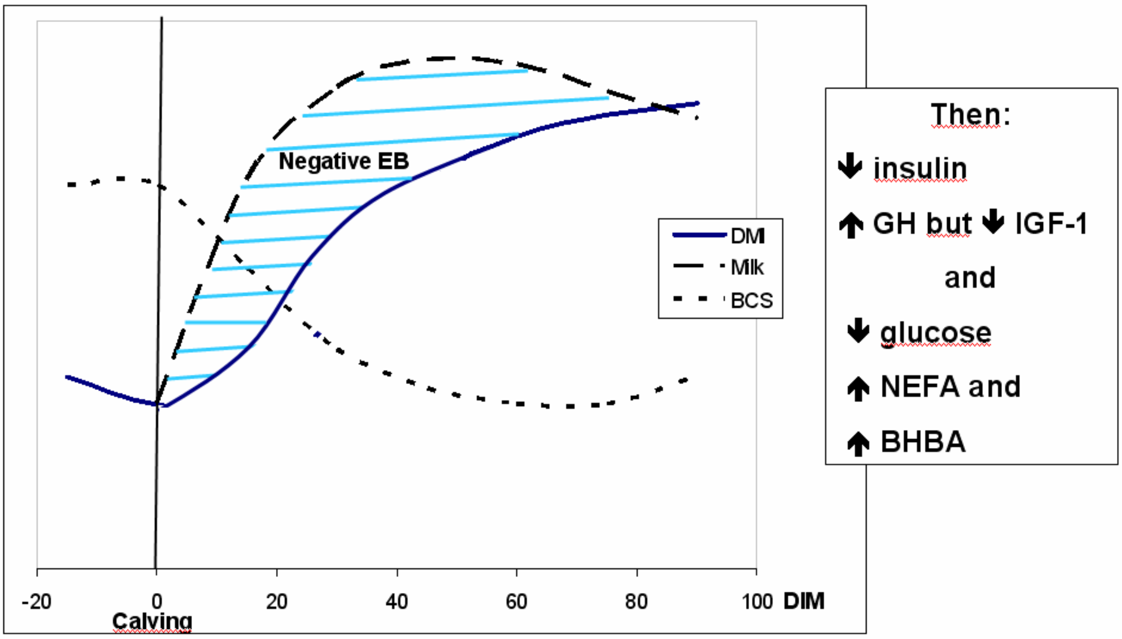

Figure 1 - Changes of milk yield, DMI and BCS in the first part of lactation of High Yielding Cows.

Factors affecting milk yield

Very shortly, MY is consequence of the number and activity of mammary gland cells, which in turn depend on the genetic background, on parity and on more or less optimal physiological conditions affecting endocrine and metabolic balance. In the very early lactation it appears obvious that homeoretic mechanisms tend to prevail on the homeostatic ones; therefore milk production is increased independently from DMI (at least in part). Again, this confirm that milk yield is not driven by DMI.

Factors affecting Dry Matter Intake

The MY does not seem the main factor of DMI changes, in fact, according to Martens (2007), reducing the daily DMI of lactating cows from 25.2 kg to 12 kg per day, no proportional reduction in milk production was observed, instead, productivity was maintained by rapid mobilisation of body reserves. This is particularly evident in the transition period of early lactation, and obviously it causes a higher loss of BCS; however, it is worthwhile to understand which other factors can be responsible of the different rate of DMI raise after calving. In fact, some aspects of dairy cows management, either before and after calving, appear to be important.

What happens before calving can be surprising because there are no difficulties to cover the requirements (Douglas et al., 2006), except immediately before delivery when a DMI reduction of 35% occurs in cows suggesting a increase of energy concentration of the diet in the so called close-up (Grummer, 1995). On the contrary, since the Rukkwamsuk et al. (1999a and 1999b) experiments, the pre-calving feeding must avoid the overconditioning of cows and furthermore, according to recent experiments of Drackley (personal communication), dry period diet would be of low energy content (80-100% of NRC suggested requirements). To similar conclusions has recently arrived Grummer et al. (2007): "Approximately 15 years ago, our research group strongly recommended that producers feed moderate-energy diets to pre-fresh transition cows. Today, after many research trials, it has become obvious that we were in error and there was not sufficient evidence to make such recommendations". Confirming that "low" energy diet, particularly in the far-off period, allows a lower reduction of DMI at the end of pregnancy and this result is of great importance because, as demonstrated by Grummer (1995): "the DMI of the day before calving is correlated to the DMI of the 21st day of lactation".

Despite more obvious, the management utilized after calving, need some explanations; the first idea could be the highest (as possible) increase of energy concentration of the diet to compensate the lower gastro-intestinal capacity (and DMI too). Thus, Rabelo et al. (2003 and 2005) findings suggest that "energy density of prepartum diets has a minor influence on postpartum metabolic status of cows compared with energy density of diets fed during the first 3 wk of lactation. A more favourable milk yield and DMI rise, as well as better metabolic profile occurs when increasing the concentrate content of the diet immediately postpartum compared with delaying the increase until d 21 postpartum". This could in fact contribute to the reduction of feed bulk space and contemporary to increase nutrient availability (more DMI and more digestible) leading to improve energy balance with a lower NEFA and keton bodies levels. On the contrary, the high level of NEFA and low of glucose could impair fat metabolism with keton bodies production (Drackley, 1999). The ketone bodies are well known to cause a lower DMI when above 1,4-1,5 mM/l and the primary cause is in fact the excess of energy output (milk yield), respect to the feed input (primary ketosis).

A secondary cause of ketosis and perhaps more frequent, is the case of metabolic or infectious diseases which reduce DMI (then glucose availability), while NEFA release can be higher (inflammation increases lipolysis).

Unfortunately, the high energy density of the diet, particularly in case of high fermentable carbohydrates, can be associated to a consistent decrease of rumen pH (acidosis) which can cause a reduction of DMI (and of course of energy) (Allen, 1997). Rumen acidosis is moreover a cause of many health problems (Nocek, 1997; Gozho et al., 2005). High fat content (above 5-6% of DM) can also causes some rumen problems for the interferences with its micropopulation and can reduce the diet palatability.

The above suggestions seem to us to confirm that the diets of dry and transition periods have to be evaluated with some cautions if maximum DMI is the objective; in fact, of great interest appears some literature observations:

- "… that physical capacity of the rumen is not the causative factor of prepartum intake depression" (Park et al., 2001);
- " … factor other than physical constraint must be playing a major role in the regulation of voluntary intake in early lactation" (Ingvartsen et al., 1999);
- the changes in gastrointestinal and liver mass during transition – essential for the progressive rise of intake – were apparently a consequence of changes in DM intake and nutrient supply and not initiation of lactation per se (Reynolds et al., 2004).

Dry Matter Intake and "disease"

In other words, it can be concluded that, before and after calving, factors different to those more traditionally considered (energy density, fermentability, fat content, milk yield level, "rumen" space etc.)

would be evaluated. Thus, we consider noteworthy our partly published (Trevisi et al., 2002), results which have demonstrated a good and negative relationship between dry matter intake reduction in the last part of pregnancy and the blood indices of inflammatory conditions (haptoglobin and ceruloplasmin). Of particular interest is the fact that this DMI reduction occurred at different time from calving: 7-10 days, 4-5 days or never and the agreement with inflammatory indices before calving was always remarkable. Furthermore, excluding – as we did in advance - animals with clinical or subclinical problems at calving and immediately after it, the animals showing a more precocious and strong DMI reduction (before calving) have showed a lower DMI in the whole first month of lactation; moreover, any relationship has been observed with the milk yield. It was higher in group with the earliest reduction of DMI, which cows had the highest BCS values at the beginning (3.4 points), but also the highest losses in the first month of lactation. Very interesting are the conclusions of a recent paper by van Knegsel et al. (2007): "…NAb (natural antibodies) concentrations binding KLH (keyhole limpet hemocyanin) and LPS (lipopolysaccharide) in plasma had a positive relation with EB (energy balance). Hereby, our data indicate that a NEB in dairy cows in early lactation can be associated with compromised innate immune function".

The results are not surprising because, among the other factors affecting feed intake, the sickness (and particularly the effects of pro-inflammatory cytokines) has a great influence. The mechanisms have been described by Johnson (1998) and more recently by Johnson and Finck (2001); they involve a direct effect of IL-β, IL-6 and TNFα on the brain receptors, but also an increased secretion of leptin by TNFα. The cytokine are "hormones" mainly released by the cells of immune system when stimulated, but not only in case of clinical diseases; it happens in fact that they could be released in case of: parasites (in- or out-side), subclinical diseases (mastitis, lameness etc.), digestive problems (abomasal ulcers, liver abscesses, rumen acidosis, SARA etc.), tissue damages (at calving time for distocia, milk fever etc.), heavy exercise as labour can be, many kind of stresses and particularly the oxidative one, which in turn can occur as consequence of another inflammation. Therefore, inflammation is per se a cause of prolonged (reiteration) inflammation for the release of reactive oxygen species which activate nuclear factor kappa B (NFkB) which is cause of new cytokines and COX release (Rimbach et al., 2002). Finally, at calving or immediately before it, cytokines can be released by placenta (as observed in humans); while after calving, a very frequent cause of inflammation start can be the retained placenta or anyhow the uterus involution (with some opportunistic bacteria invading it).

Therefore it cannot be surprising if our lab (Cappa et al., 1989) pointed out that a large proportion of cows, despite clinically healthy, as confirmed by Bertoni et al. (2008), at the beginning of lactation show blood changes as indices of acute phase response. Therefore, whatever the cause of release, they seems to be responsible of a lower DMI in the transition period; furthermore, they can impair the energy balance because the inflammatory phenomena rise the energy cost of maintenance with a lower efficiency: 10-15% less, according to our results (Trevisi et al., 2007). These inflammations phenomena are however responsible of slightly lower milk yield, but definitively lower fertility (Bertoni et al., 2008). This is confirmed by our results on cows treated with "aspirin" 3-5 days immediately after calving: high milk yield (Figure 2), better health and fertility (Table 1).

Feeding rules of dairy cows

It is well known that almost never the dairy cow is fed to cover the actual requirements; reproduction cycle is characterized by an accumulation stage (particularly at the end of pregnancy) and by a mobilization one (particularly in the early lactation): cow body is like an "accordion " (Figure 1). At least in lactation, other criteria have therefore to be followed and according to previous statements, what is essential in dairy cows feeding can be summarized within the followings:

- before calving to ensure constant (relatively high) DMI till delivery and to minimize metabolic diseases (and infectious as well) around calving: retained placenta, milk fever, displaced abomasum etc., but also mastitis, lameness etc.;

after calving ensure a quick rise of DMI (and energy-protein too), but remembering that – at least for high yielding cows – some BC losses are unavoidable. Therefore, the opposite risks of ketosis (shortage) and of acidosis (excess) must be avoided, while special care has to be taken to avoid any disease and to optimize gut-liver functions and the immune system activity.

Nevertheless, it is noteworthy that not only feeding, but other aspect of animal management (defined "subclinical stressors" by Drackley et al., 2005) can be also important to be considered with the aim to get the above mentioned objectives, namely of good health and welfare.

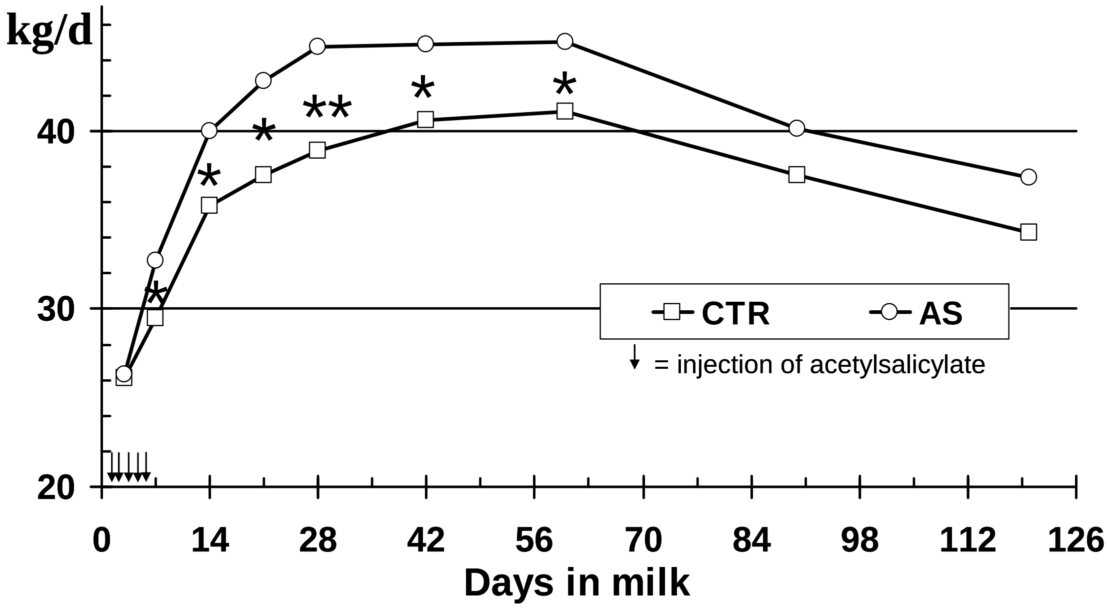

Figure 2. Milk yield till the 4th month of lactation in cows treated (AS) or not (CTR) with lysine acetylsalicylate during first 5 days after calving (P<0.05; ** P<0.01). (Trevisi and Bertoni, 2008).*

Dry period management

Stated in advance that for many reasons the dairy cow would reach the 7th month of pregnancy in a good BCS and that dry period would be "pretty" short (40-55 days), but it would remain (Grummer, 2006). What is important in the dry period, is:

- to maintain a proper energy-protein balance to cover energy and protein needs (maintenance plus foetus), but also to guarantee the proper microbial population into the rumen;
- to maintain some homeostatic mechanisms well "trained" to respond to the parturition- lactation challenge. The better known among these is the calcium (and perhaps phosphorus) which levels have to be "borderline" of deficiency, to avoid "old" cows could fail, causing the milk fever. Nevertheless, other important "mechanisms" could be the antioxidative systems which are based upon nutrients-nutraceuticals which must be available in proper amounts (vitamin E, β carotene, poliphenols, etc.), but also on enzymatic systems (SOD, paraoxonase, glutathione peroxidase etc.)

Table 1. Main fertility indices observed in cows treated (AS) or not (CTR) with Lysine acetylsalicylate in the 5 days after calving (Trevisi e Bertoni, 2008).

group		CTR	AS
cows	*n°*	24	24
culled cows	*% of total*	16.7	8.3
pregnant cows	*% of total*	83.3	91.7
pregnant at 1st insemination	*% of pregnant*	21.1	52.4
repeat breeders	*% of pregnant*	36.8	28.6
services per pregnancy (§)	*n°*	2.68	2.38
days open (§)	*n°*	131.8	106.3
Fertility Status Index (FSI) (@)	*n°*	12.6	61.8

LEGEND: (§) after logarithmic tranformation; (@) Esslemont and Eddy (1977).

with essential trace elements part of their molecules and that would be "induced" or maintained at high level in some way to be available at right time (how can it be done?);
- to minimize any health problem (or cause of cytokine release), but also minimize the inflammatory response (how?). To do this, non feeding tools are the hygienic means, but also prophylaxis (vaccines, antiparasitics, good mastitis treatments, feet care etc.), as well as the reduction of distocia (i.e. small calve sires) and the avoidance of stress conditions at calving time. From feeding point of view it means to maximize immune system capacity (appropriate nutrient supply), but also to prevent metabolic and digestive diseases which can occur more frequently around calving (milk fever, retained placenta, rumen acidosis etc.).

According to recent suggestions of Drackley (personal communication), but corresponding to the feeding rules developed in our Institute (Bertoni et al., 1997) the proper diet of the last 40-50 days of pregnancy are:
- "low" energy concentration (1.2-1.3 Mcal/kgDM);
- acceptable crude protein concentration (11-12% DM);
- high fiber;
- "low" Ca and P (as well as Na and K);
- good trace elements and vitamin supply;
- steaming-up or close-up can be avoided or to be short and light.

Early lactation management

After calving, feeding is driven by milk yield and by DMI, both directly or indirectly affected by:
- genetic background which increase the number-activity of the mammary gland, as well as the partitioning of nutrients between body tissues and mammary gland (more or less milk yield);
- health (in the widest meaning) which can modify yield and dry matter intake.

However, the rise of DMI is partly independent from milk yield and it takes a much longer time to reach the maximum respect to milk yield – according to our experience it takes 20-30 days after lactation peak – furthermore it can be slower (often cytokine effect) with higher risks for a bad NEB.

Therefore what have to be obtained in this period are the following objectives:
- to guarantee good health conditions;
- to maximize the feed intake without to compromise the rumen-intestine functions.

This means, in case of TMR for high yielding cows, a diet with the highest energy and protein contents, although safe for rumen and intestine bacteria:
- high fermentable starch-sugar (26-28% on DM) and low fermentable cellulose/hemicellulose (32-36% of DM as NDF);
- high (enough) physically efficient fiber (rumination activity) (e.g. 75% of NDF from forages);
- appropriate protein content (16-17% on DM) with enough soluble-degradable proteins (30% and 65% of crude proteins) to ensure an optimal bacteria growth/activity for a "long" time, but also undegradable-digestible proteins (36-38% of crude protein) to cover the early lactation high requirements despite the lower DMI;
- some fat (4.5-5.5% of DM), some of them "protected" (Ca-soaps, cotton seeds, etc.);
- good minerals (macro as well as trace elements) and vitamins;
- proper rumen, but also intestine, buffers to avoid acidosis and therefore the risk of digestive diseases with their more or less dangerous consequences.

Conclusions

To conclude, the feeding rules of dairy cows have to be calibrated not to cover immediate requirements, but to "control" the "accordion like" evolution of the body storages; renewed in late lactation, avoided in the dry period and slowly reduced in the first weeks of lactation. However, while the nutritive values of pregnant cow diets do not seem to be affected by the production level, after calving the TMR mixture must be more or less concentrated according to the expected milk level. Namely, two extremes have to be avoided:

- of energy defect with too high mobilization and immediate risk of ketosis and later on of low fertility;
- of too high fermentability or fat levels (both compromising the digestive function).

Nevertheless, the most critical point seems to be the evolution of DMI in the transition period: it has to be maintained at good level before calving and it has to grow fast after it. The peculiarities of this aim are however:

- diet before calving must be "rich" in fiber;
- diet after calving must be "rich" but safe;
- maybe more important is the "health" status because clinical, but also subclinical, disorders with pro-inflammatory cytokine release, cause a more or less important reduction of dry matter intake (which is highly correlated to the degree of Negative Energy Balance).

For this last aspect, not only feeding but careful management, prophylaxis, hygiene, etc., are of paramount importance from dry period to the end of 1st lactation month.

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