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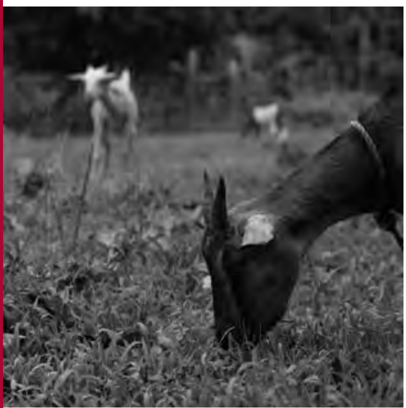

paper

ENHANCING ANIMAL WELFARE AND FARMER INCOME THROUGH STRATEGIC ANIMAL FEEDING

Some case studies

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175

FAO ANIMAL PRODUCTION AND HEALTH
paper

ENHANCING ANIMAL WELFARE AND FARMER INCOME THROUGH STRATEGIC ANIMAL FEEDING

Some case studies

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Contents

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Preface

Good nutrition is the fundamental requirement for all farm animals and it is considered as one of the biggest contributors to animal welfare. Improper nutrition not only affects productivity but also the health, behaviour and welfare of an animal. At the same time, the safety and quality of the food chain is indirectly affected by the welfare of farm animals due to the close links among animal welfare, animal health and food-borne diseases such as *Escherichia coli, Salmonella, Campylobacter,* etc. Stress factors, poor welfare and imbalanced nutrition can increase susceptibility to diseases among animals, thus increasing the need for veterinary treatment, posing risks to food consumers, decreasing profitability and endangering environmental sustainability of the livestock production systems and of the associated animal food chains.

Increasing worldwide demand for animal products is imposing a huge strain not only on the natural resources but also on farm animals. In intensive production systems, animals are being pushed towards maximizing productivity, while in the extensive and smallholder systems in developing countries animal productivity and welfare are compromised by inadequate nutrition. Even in intensive production systems where animals receive abundant nutritious diets, animal welfare could be impaired due to excessive or inappropriate feeding. An array of management-related factors – such as housing and bedding, restraining systems, space and crowding, transport conditions, stunning and slaughter methods, castration of males and tail docking – affect welfare.

A large body of literature exists on how these factors impact on animal welfare, health, productivity and product quality, but little attention has been paid to understanding the linkages between animal nutrition and animal welfare. This knowledge is a pre-requisite for drawing up policy options and guidelines for establishing livestock production systems that are humane, socially acceptable, efficient and environmentally friendly.

Farmers find it difficult to adopt practices that promote animal welfare without having sound information on the impact of such practices on animal productivity and their income. Any such practice that does not increase farmers' incomes is unlikely to be followed, especially in developing countries.

At the Expert Consultation held at FAO headquarters in Rome in September 2011, participants called for a series of case studies to document existing practices that enhance animal welfare as well as farmers' incomes; currently, such studies are few and far between.

This document presents a number of such studies and it is hoped that the information they contain will encourage researchers and agencies working in the area of animal welfare to initiate studies to capture the impact of any intervention on farmers' incomes – an area that has been neglected to date. It is also envisaged that these studies could pave the way for developing guidelines and policy options to promote sustainable animal feeding that enhances animal welfare, animal productivity, animal product quality and profitability.

Reducing variability in nutrient consumption: Improving health, welfare and profitability of dairy cows fed total mixed rations

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MAIN MESSAGES

- Selective consumption, or sorting, of lactating dairy cow diets leads to increased variability in nutrient intakes. Specifically, cows consume less long forage particles than expected, leading to depressions in rumen pH, and greater risk of subacute ruminal acidosis (SARA).
- Dairy cattle with SARA face poor feed efficiency, reduced feed digestibility and microbial protein synthesis, reduced milk fat, inconsistent dry matter intake, as well as increased incidence of other diseases, including diarrhoea, ruminal ulcers, parakeratosis, liver abscesses and laminitis.
- These negative consequences of SARA on dairy cow welfare and producer profitability, combined with the high prevalence of this condition, constitute a significant concern for the dairy cattle industry.
- To reduce the risk of SARA and its resultant impacts on dairy cow welfare and profitability, producers can implement several dietary and non-dietary nutritional measures to reduce the degree of feed sorting, including: increasing the proportion of dietary forage content, reducing forage particle length, adding water to dry diets, adding molasses-based liquid feeds to wet diets, and providing fresh feed more often throughout the day.

ACRONYMS

DMI	dry matter intake
NDF	neutral detergent fibre
peNDF	physically effective (neutral detergent) fibre
TMR	total mixed ration
SARA	subacute ruminal acidosis

INTRODUCTION

Maintaining healthy animals is a key component of animal welfare. Ensuring good rumen health in dairy cattle is key for the maintenance of efficiency and productivity, and thus herd profitability. In dairy cattle, the rumen environment is designed to function optimally within a pH range of 6.2–7.2. To maintain healthy rumen function, dairy cows require diets that contain adequate amounts of physically effective fibre (peNDF). Ensuring adequate intake of peNDF can be difficult because most commercial dairy rations, designed to maximize milk production, contain high levels of concentrate and high-quality forages, often limiting in peNDF (Beauchemin and Yang, 2005). When ruminants consume excessive amounts of rapidly fermentable (non-fibre) carbohydrates, combined with low intake of peNDF, they are not able to maximize their rumination time and salivary buffer flow to the rumen, and thus ruminal pH drops below normal physiological levels. Sub-optimal ruminal pH (e.g. pH 5.2–5.8) is often referred to as subacute ruminal acidosis (SARA) (Owens *et al.*, 1998).

SARA is a major concern in terms of both productivity and animal welfare. Rumen pH<5.8 is harmful to ruminal cellulolytic bacteria (Russell & Wilson, 1996) and SARA is thus detrimental to fibre digestibility. As result, dairy cattle with SARA are less profitable because of poor feed efficiency, reduced feed digestibility and microbial protein synthesis, reduced milk fat, and inconsistent dry matter intake (DMI). They also face increased incidence of other diseases, including diarrhoea, ruminal ulcers, parakeratosis, liver abscesses and laminitis (Krause & Oetzel, 2006; Plaizier *et al*., 2008).

Despite our vast knowledge of the etiology of SARA and its consequences, the prevalence of this digestive condition, which is estimated to range from 19 to 29 percent in dairy cows in early- and mid-lactation, remains very high because we try to maximize milk production through encouragement of maximum intake of diets containing high proportions of highly-fermentable carbohydrates (Krause and Oetzel, 2006).

This case study focuses on how dietary selection (sorting) of dairy rations may lead to depressed rumen pH, thus increasing the risk of SARA. Through a series of research studies, we have established evidence indicating that excessive sorting of certain ration components by dairy cattle can lead to SARA and also promote variability in nutrient intake. We have also investigated the impact of this resultant health condition on cow productivity and, thus, also profitability. Finally, a discussion of means to reduce this behaviour is outlined.

FEED SORTING AND INTAKE CONSISTENCY

Dairy cattle are commonly fed their feed components in the form of a total mixed ration (TMR). Total mixed rations are designed as a homogenous mixture with the goals of helping to minimize the selective consumption of individual feed components by dairy cattle, promoting a steady-state condition conducive to continuous rumen function and ingesta flow, and ensuring adequate intakes of fibre (Coppock *et al*., 1981). It is not surprising that providing feed as a TMR is standard on most commercial dairies, particularly for lactating animals. Unfortunately, even when providing feed as a TMR, cows have been shown to preferentially select (sort) for the grain component of the TMR and discriminate against the longer forage components (Leonardi and Armentano, 2003). To date, our collective research has demonstrated that, on average, when dairy cows are fed TMR they selectively consume approximately five to ten percent more of the smallest ration particles and ten to

20 percent less of the longest ration particles than that which we would predict they would consume based on the original ration formulation.

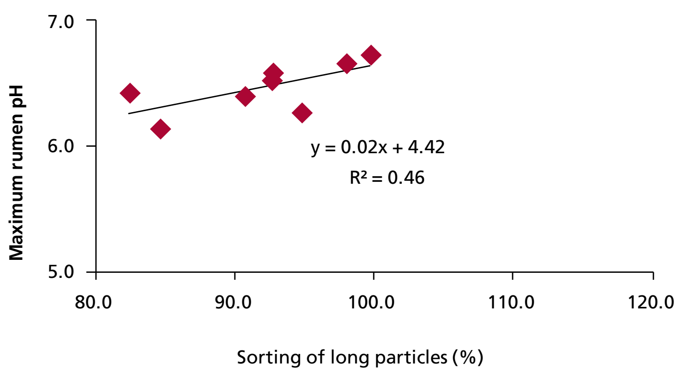
IMPACT OF FEED SORTING ON RUMEN HEALTH AND PRODUCTIVITY

The result of sorting of TMR by dairy cows can, therefore, be that the ration actually consumed by cows is higher in fermentable carbohydrates than intended and lower in effective fibre. Such nutrient consumption patterns lead to excessive acid production and reduced buffering capacity in the rumen. Not surprisingly, therefore, we have demonstrated that such consumption patterns are related to depressions in rumen pH (Figure 1; DeVries *et al.*, 2008) and, thereby, increase the risk of SARA. In fact, we have been able to explain between 45 and 97 percent of the variability in measures of rumen pH (minimum, maximum, mean and range) based on the feed sorting patterns of lactating dairy cows (DeVries *et al.*, 2008).

Given the relationship between sorting and rumen pH, and the fact that depressed rumen pH may lead to milk fat depression, it is not surprising that we have recently demonstrated a clear association between sorting against long ration particle and producing milk of lower fat percentage. In two recent separate studies, we observed that milk fat decreased by 0.15 percent for every 10 percent refusal of long forage particles in the ration (DeVries *et al.*, 2011; Fish *et al.*, 2012). Sorting of a TMR can also reduce the nutritive value of the TMR remaining in the feed bunk, particularly in the later hours past the time of feed delivery (DeVries *et al.*, 2005) after the greatest amount of sorting has already occurred (Hosseinkhani *et al.*, 2008).

Figure 2 illustrates how feed sorting deteriorates nutritional value, as indicated by the quadratic increase in fibre content in the feed remaining in the feed bunk throughout the course of the day. For group-fed cows, this may be detrimental for those cows that do not have access to feed, at the time when it is delivered, for example when there is high competition at the feed bunk or when lameness incidence is high. In such cases, cows that are forced to return to the feed bunk at later time points during the day may end up

FIGURE 1
Association between sorting (% of actual intake relative to predicted intake) of long ration particles (>19 mm screen) and maximum rumen pH



Source: Adapted from DeVries *et al.* (2008).

consuming a ration very different from that originally formulated for them and may, thus, not be able to maintain adequate nutrient intake to maintain high levels of milk production (Krause and Oetzel, 2006); whereas those accessing the feed bunk for a greater period earlier in the day are more likely to experience SARA because of selective intake of highly-fermentable feed particles.

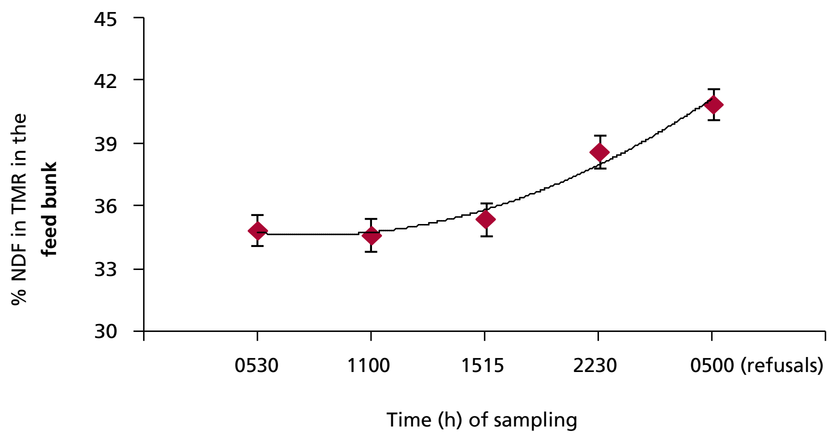
ECONOMIC COST OF FEED SORTING AND SUBACUTE RUMINAL ACIDOSIS

Reduced profitability associated with feed sorting and any resultant SARA is related to both direct and indirect costs. As noted above, our research has indicated that milk fat decreases by 0.15 percent for every ten percent refusal of long forage particles in the ration (DeVries *et al.*, 2011; Fish and DeVries, 2012). The financial impact of such a drop in milk fat is substantial, particularly in areas where milk value is related to component prices. For example, a ten percent refusal of long ration particles in a 500-cow Canadian dairy herd may result in approximately 90 000 Canadian dollars in annual lost revenue due to production of less milk fat. Indirect costs of sorting, including greater within-herd variability of nutrient intakes, would add to this decrease in profitability.

The direct financial impact of SARA was demonstrated by a field study on a large dairy farm in New York State where it was found that SARA reduced milk yield by 2.7 kg/day, milk fat production by 0.3 percent and milk protein production by 0.1 percent (Stone, 1999). These production losses associated with SARA alone were estimated to be US$1.12/day/cow (Stone, 1999). To place that cost in further context, if a 1 000-cow dairy herd had a 25 percent prevalence rate of SARA, the production losses associated with SARA would be approximately US$102 200 annually. These costs exclude the indirect financial impact of associated disorders and risks (such as lameness, reduced reproductive efficiency and increased culling) and veterinary treatment, which would be in addition to the cost of lost milk production.

FIGURE 2

Change in neutral detergent fibre (NDF) content of the ration remaining in the feed bunk over the course of the day as the ration is being sorted



Source: Adapted from DeVries *et al.* (2005).

REDUCING THE DEGREE OF SORTING OF TOTAL MIXED RATIONS

As described above, the high-energy diets, which are low in neutral detergent fibre (NDF) and high in starch, that are typically fed to lactating dairy cows can put the cows at risk of SARA. Interestingly, our research indicates that lactating dairy cows demonstrate higher degrees of sorting against longer forage particles and for smaller grain concentrate particles when fed lower forage diets (DeVries *et al*., 2007; 2008). Thus, in situations where rations are being heavily sorted, it is recommended that a greater proportion of forage be included in the ration. Besides the quantity of forage, the type and particle size of forages will also affect feed sorting (Leonardi and Armentano, 2003). A greater proportion of dry forage (hay) in the ration will increase the amount of sorting against longer fibrous particles. Greater particle size of forages, including alfalfa hay and corn silage, also results in increased sorting against long forage particles in the TMR. Thus, sorting can be reduced by chopping forages into smaller lengths; however, care must be taken in those situations not to reduce particle size to the extent that the forage loses its physical effectiveness for stimulating rumination and rumen buffering.

Beyond changing forage characteristics or content, sorting can be influenced by other dietary measures. It is commonly believed that adding water to a dry TMR will help bind particles together and make it harder for dairy cattle to sort out smaller particles. Research has shown that the amount of feed sorting (against long particles) can be reduced when water is added to a dry TMR (>60 percent dry matter), particularly those rations containing a high proportion of dry forage (Leonardi *et al*., 2005; Fish and DeVries, 2012). Recent research has also indicated that for wetter rations, other liquids (for example, a molasses-based liquid feed) may be more effective at reducing feed sorting (DeVries and Gill, 2012). It is recommended that in situations where sorting of mixed rations is evident, producers try adding water or liquid feed to their TMR, and carefully monitor the effects that these may have.

There are also feeding management practices which influence the degree of feed sorting. Increasing the frequency of TMR delivery from once per day to twice (or more often) per day has been shown to reduce feed sorting (DeVries *et al.*, 2005; Endres and Espejo, 2010). Given this, and the fact that more frequent feeding also promotes more equal access to freshly delivered feed and a more even distribution of feeding time over the course of the day, feeding cows more often has the potential to reduce the variation in composition of ration consumed.

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Improving the welfare of dairy goats: Feeding behaviour identifies goats at risk of subacute rumen acidosis

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MAIN MESSAGES

- Feeding behaviour is highly variable between animals.
- Feeding behaviour modifies rumen pH pattern and occurrence of subacute ruminal acidosis (SARA).
- Avoiding SARA increases animal welfare, milk production and therefore farm profitability.

ACRONYMS

CP crude protein
DMI dry matter intake
NDF neutral detergent fibre
PCA Principal Component Analysis
SARA subacute ruminal acidosis
SD standard deviation

INTRODUCTION

High-concentrate, low-forage, energy-dense diets are often fed to ruminants in intensive systems as a means of achieving high growth rates and high levels of milk production. These highly fermentable diets are associated with reduced chewing, decreased rumination and decreased saliva production which can limit the buffering capacity of the rumen, and thus often causes rumen acidosis (extended periods where rumen pH falls below 6.0).

To date, the majority of work in this area has focused on dairy and beef cattle, specifically in terms of rumen function and the negative effects of this disease on animal health and production, including prolonged periods of feed refusal, decreased performance, metabolic acidosis, dehydration, laminitis, polioencephalomalacia and liver abscesses (Owens *et al.*, 1998). Although acute acidosis is easily diagnosed, subacute ruminal acidosis (SARA) often goes undetected because subclinical signs are less pronounced. The tremendous individual differences between animals within a herd and the fact that not all animals succumb to this disease at the same time make this a particularly challenging disease for farmers to manage.

Clearly, the welfare of animals succumbing to acidosis or SARA is reduced. A recent study on dairy goats by Desnoyers *et al.* (2011) provides compelling evidence that individual differences in feeding behaviour between lactating goats can impact the severity of this disease and thus impact animal welfare. The aim of this paper is to expand on the original work of Desnoyers *et al*. (2011) by first describing the relationship between feeding behaviour and rumen pH and then estimating the potential animal welfare and possible economic costs resulting from SARA by describing the impact of SARA on milk production in dairy goats.

CASE STUDY

The study of Desnoyers *et al*. (2011) used 12 rumen cannulated dairy goats (eight Alpine and four Saanen) in mid lactation (6^{th} to 17^{th} week of lactation) that were housed in individual pens. It was carried out according to French legislation on animal experimentation in line with the *European Convention for the Protection of Vertebrates used for Experimental and other Scientific Purposes* (European Directive 86/609).

At the start of the experiment, the average body weight of the goats was 65 ± 7.4 kg (Mean ± SD) and the milk yield per day was 3.5 ± 0.58 kg. Animals had free access to water and were fed a total mixed ration *ad libitum* (ten percent refusals). The percentages of the different components of the diet were, on a dry matter basis: 50 percent concentrate blend (25 percent wheat, 25 percent barley, 30 percent maize, 15 percent soybean meal, three percent molasses and two percent mineral premix), 35 percent grass hay and 15 percent pressed sugar beet pulp. On a dry matter basis, the neutral detergent fibre (NDF) content was 34.7 percent and the CP content was 12.7 percent. Goats were fed two-thirds of their daily ration at 16:00 and the remaining one-third at 08:00. They were milked twice daily at 15:30 in the afternoon and 7:30 in the morning.

Each goat was fitted with a leather halter that measured feeding behaviour (time spent eating, ruminating or jaw resting) and a self-cleaning indwelling rumen pH probe that provided continuous pH measurements every minute. The pH probe was introduced into the rumen through the cannula and linked to a portable device placed in one of the pockets of a coat covering the back of the animal. All goats had previous experience with the halter device. Given that two-thirds of the total daily feed was offered in the afternoon, the data used for this case study was limited to the time between the afternoon delivery and the morning milking time (15 hours and 20 minutes). There was no human activity during this time period minimizing any external influences on the feeding behaviour measurements.

Outcome measures (rumen pH, eating, ruminating and jaw resting durations) were summarized in forty-six 20-minute intervals, when available, for the 11-week experimental period. Some data were lost due to technical issues resulting in only 333 feeding patterns measures for the 12 goats. A feeding pattern corresponded to data from one goat and one day.

Principal Component Analysis (PCA) was performed on the cumulative time spent eating and the cumulative time spent ruminating within each of the forty-six 20-minute intervals; these were treated as 92 potentially independent variables (with 46 measures per variable) in the PCA. The first two components of the PCA explained 11.3 percent of the total variance, which is a reasonable proportion given the high number of variables involved (92). We also observed an inverse relationship between eating and ruminating on the first component, particularly during the first three hours following the afternoon feeding. To describe the individual variation observed in feeding patterns between animals, the 33 patterns (representing 10 percent of the total number of patterns), that were to the extreme left and the other 33 patterns that were to the extreme right of the first principal component were selected.

The mean value for the 33 feeding patterns that were to the extreme left (Group 1A in the paper of Desnoyers *et al.*, 2011) represented the goats that had a large first period of feed intake immediately after feeding, followed by a period of increased rumination during the night and another period of intake in the early morning hours. In the second set (Group 1B), the 33 patterns at the extreme right, the goats had a relatively short first period of intake after feeding, followed by a period of rumination and then a second major period of intake about t to five hours after feeding (Figure 1).

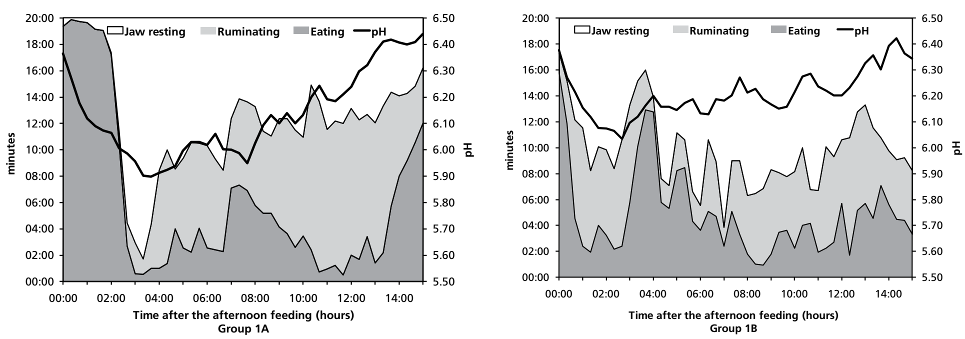
Unlike the first group, this latter group alternated eating and ruminating periods during the night and in the early morning hours.

The dry matter intake expressed on a body weight basis (38.8 ± 9.54 g/kg BW; Mean ± SD), the time spent eating (124 min ± 53 min/kg DMI), and the time spent ruminating (103 min ± 42 min/kg DMI) were all similar for both groups. However, given that the goats in group 1A were heavier (62.9 ± 6.32 - Mean ± SE) than those in group 1B (54.9 ± 9.60 kg), they consumed more feed on a daily basis than the goats in Group 1B (2.57 ± 0.558 vs 1.97 ± 0.647 kg DMI/day).

Although there were no differences in the daily mean rumen pH values (Group A: 6.07 ± 0.352 vs Group B: 6.21 ± 0.227) between the two groups, we did observe large differ-

FIGURE 1*

Time spent eating, ruminating or jaw resting, and rumen pH



Note: Measurements were taken at 20 minute intervals during the 15 hours and 20 minutes following the afternoon feeding for the 10 percent of patterns at the extreme left and the extreme right (Groups 1A and 1B) on the first axis of the Principal Component Analysis based on the time spent eating and the time spent ruminating during each of the 46 intervals of 20 minutes following the afternoon feeding that also had measurements of rumen pH (22 and 13 patterns, for Groups 1A and 1B, respectively).

* Reprinted from Desnoyers M., Giger-Reverdin S., Sauvant D. & Duvaux-Ponter C. 2011. The use of a multivariate analysis to study between-goat variability in feeding behavior and associated rumen pH patterns. Journal of Dairy Science 94(2): 842-852, Copyright (2011), with permission from the publisher.

ences between the groups in the rumen pH patterns. The rumen pH in the goats that had a pronounced first period of intake followed by a period of night rumination (Group 1A) decreased pH quickly and remained below the threshold of 6.0 for approximately five of the 15 hours and 20 minutes, compared with the pH of the goats from the other group which was slightly below 6.0 for only one hour (Figure 1). Given that extended periods where rumen pH is below 6.0 is a known risk factor for SARA, we are confident that these goats were suffering from SARA.

The milk production for Group 1A was 1.33 kg milk/kg DMI and for Group 1B was 1.50 milk/kg DMI. Although this study was not intended to determine the effects on milk production, the fact that the goats that produced 0.170 kg more milk/kg DMI also had feeding behaviour patterns that resulted in improved rumen pH patterns is of interest and warrants further investigation.

From a practical point of view the results in the current study, together with those of Giger-Reverdin *et al*. (2009) suggest that the amount of feed consumed in the 90 minutes after feeding may be a useful indicator identifying which goats within a herd are at risk of SARA. We strongly encourage further research to determine the effects of improved feeding behaviour patterns on farm income over feed costs.

CONCLUSION

All goats in the present study were provided the same diet but differences in their individual feeding behaviour patterns determined whether they were more or less at risk of succumbing to SARA. Although all goats consumed approximately the same amount of dry matter intake (expressed on a body weight basis) and had similar chewing durations (expressed on a dry matter intake basis), those animals which alternated eating and ruminating periods minimized the amount of time their rumen pH fell below the threshold value of 6.0. It follows that these goats were less likely to suffer from SARA and thus had improved welfare. Moreover they produced about 170 g more milk per kg DMI and thus were likely to contribute more to total farm income over feed costs arising from milk sales.

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Yerba Mate (*Ilex paraguariensis*) as strategic supplement for dairy cows

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MAIN MESSAGES

- Yerba mate supplementation results in lower degree of oxidative stress.
- Oxidative stress biomarkers – reactive oxygen metabolites (ROMs) and biological antioxidant potential (BAP) – can be considered as new and reliable indicators of animal welfare.
- Yerba mate supplementation of diet of dairy cows improves their productive and reproductive performances.
- The use of alternative feedstuff like yerba mate in dairy nutrition represents a novel management procedure that can increase farms profits and is extremely easy to use.

ACRONYMS

AOPP advanced oxidative protein products
BAP biological antioxidant potential
BCS body condition score
DM dry matter
LW liveweight
OSI oxidative stress index
ROM reactive oxygen metabolite
YM yerba mate

INTRODUCTION

On-farm animal husbandry practices are intrinsically linked with animal welfare. To deliver quality dairy products and safe food efficiently, dairy farmers must practise good animal husbandry and maintain their animals in peak condition. The very nature of dairy farming means that sound dairy husbandry practices also deliver good animal welfare. However, the adoption of intensive methods of husbandry in dairy cows for higher milk yields might compromise their health and welfare and consequently increase the incidence of the major metabolic diseases.

In addition, the current world food crisis is leading animal scientists and farmers to reconsider the use of alternative feedstuffs for animal production. Consequently, interest in plants, plant extracts or natural plant compounds as potential natural alternatives for enhancing livestock productivity has increased.

The livestock industry must continually seek and implement alternative animal nutritional strategies which comply with consumer desire for food products that are produced in a clean, green and ethical manner. Therefore, the role and the activity of natural antioxidants not commonly present in the diets of ruminants warrants investigation. The supplementation of the diet with yerba mate, a plant known for its antioxidant properties, has the potential to improve the health and production performances of dairy cows. This paper discusses the use of alternative feedstuffs such as yerba mate (*Ilex paraguariensis*) as a novel management procedure in dairy cow nutrition.

Grazing may provide ruminants with health benefits from certain vitamins and minerals. Though fresh forages are typically considered capable of supplying adequate levels of antioxidants for dairy cattle, the availability of these compounds for lactating grazing cows is diminished when pasture availability is not adequate to meet their energy requirements. In this situation, the gap between energy required for milk production and energy intake is often met by supplementing cows with conserved forages like silage. Silage is known for its poor content in antioxidants and thus might expose cows to oxidative stress.

Evaluation of oxidative stress in ruminants is contributing significantly to understanding of the fundamental processes involved in metabolic disorders. Oxidative stress is believed to play an important role in the regulation of the metabolic activity of some organs and productivity in farm animals (Celi, 2011b). However, it is not clear whether or not the level of oxidative stress during the peripartum period could compromise animal performance. Milk production is associated with oxidative stress and, therefore, supplementation of cows' diets with antioxidants might result in an improvement of their oxidative status and productive performances.

YERBA MATE

Ilex paraguariensis, from the *Aquifoliaceae* plant family, is a native South American tree used for the production of yerba mate tea (Heck and de Mejia, 2007; Bracesco *et al*., 2011). Research on the biomedical properties of this herb had a late start and lags well behind the impressive amount of literature on green tea and coffee, which is also a reflection of the different economic development and sizes of the populations consuming the latter.

However, in the past 15 years, there has been a several-fold increase in the literature on *Ilex paraguariensis* showing antioxidant properties using chemical models and ex vivo lipoprotein studies; vasodilating and lipid reduction properties; and weight reduction properties, among others.

Several active phytochemicals have been identified in yerba mate that may be responsible for its health benefits. These are polyphenols (chlorogenic acid) and xanthenes (caffeine and theobromine), purine alkaloids (caffeic acid, 3, 4-dicaffeolyquinic acid, 3, 5-dicaffeoylquinic acid), flavonoids (quercetin, kaempferol and rutin), amino acids, minerals (P, Fe and Ca) and vitamins (C, B1 and B2). The main polyphenol identified in yerba mate is chlorogenic acid. The polyphenol concentration of mate has shown a strong correlation to its overall antioxidant capacity. Yerba mate has higher polyphenol concentration than green tea which correlates to its higher antioxidant capacity and its higher inhibition of free radicals than green tea. Polyphenolic compounds found in mate tea differ significantly from green tea because mate tea contains high concentrations of chlorogenic acid and no catechins. On average, the amount of polyphenols extracted from yerba mate is 92 mg equivalents of chlorogenic acid per gram of dry leaves (Heck and de Mejia, 2007). Polyphenols are efficient scavengers of free radicals in a number of in vitro systems and while this has been reported in several in vitro studies, there are little in vivo animal studies regarding the effects of the polyphenols contained within yerba mate with respect to their impact on exogenous antioxidant enzyme activity.

YERBA MATE SUPPLEMENTATION IN DAIRY COWS

The effect of yerba mate supplementation on dairy cows' milk yield and oxidative stress was tested during mid-lactation (Experiment 1) and the dry period (Experiment 2). The yerba mate used in both experiments was organically grown in Paraguay. The content of the packs were pelleted immediately before the beginning of each experiment and stored in feed bins.

In experiment 1, we used 16 multiparous Holstein-Friesian cows homogeneous for age (5 years), days in milk (110 ± 10 days), body condition score (BCS; 2.6 ± 0.2) and liveweight (LW; 600 ± 15 kg).

Cows were fed a typical Australian pasture-based diet (control diet; pasture plus concentrates at milking). All cows grazed kikuyu grass (*Pennisetum clandestinum*), oversown with short rotation ryegrass (*Lolium multiflorum*), and perennial ryegrass (*Lolium perenne*) and white clover (*Trifolium repens*). The cows had access to pasture between the two milkings and were grazed in accordance with the best practice of using pasture on offer and leaf stage as the criterion to flag time to graze. Because of the limited pasture availability during the experiment, maize (*Zea mays*) silage was fed to the cows (5 kg DM/cow/day) after the afternoon milking; the cows were fed the silage on a feed pad as a group. The cows received their concentrate (6 kg/cow/day; Elite Plus, Weston Animal Nutrition, Enfield, NSW, Australia) allocation twice daily at milking.

Cows were randomly divided into two groups: one group (n = 8) was fed the control diet and one group (n = 8) was fed the control diet plus 250 g/cow/day yerba mate. Yerba mate pellets were administered once a day during the afternoon milking. Cows received the dietary treatments once daily for a total of six weeks.

In Experiment 2, a total of 40 pregnant Holstein-Friesian cows homogenous for age (6.5 ± 1.6 years), BCS (3.3 ± 0.2) and (680 ± 60kg) were enrolled in the study. Cows were fed a typical Australian pasture-based diet as described above. Cows were randomly allocated to the three following dietary treatments: Control diet (n = 13), YM 250 group (n = 14): control diet + 250 g/cow/day YM; and YM 500 (n = 14): control diet + 500 g/cow/day YM. Cows received the dietary treatments once daily for a total of four weeks before calving. Because of the limited pasture availability during the trial, maize (*Zea mays*) silage was fed to the cows (5 kg DM/cow/day) after the afternoon milking; the cows were fed the silage on a feed pad as a group. The cows received their concentrate (6 kg/cow/day) allocation twice daily at milking. The 100-day in-calf rate was also measured for all cows; the 100-

day in-calf rate describes the percentage of cows that became pregnant by 100 days after calving (Larcombe *et al*., 2003).

In both experiments, blood samples were taken from all cows before the start of the administration of the dietary treatments and at monthly intervals; LW and BCS were also monitored on these occasions. Blood samples were centrifuged and plasma was analysed for advanced oxidative protein products (AOPP), reactive oxygen metabolites (ROMs) and biological antioxidant potential (BAP). The degree of oxidative stress was estimated by the ratio of (ROMs/BAP)*100 = oxidative stress index (OSI), given that the relationship between the level of oxidative stress and pathology is higher when ROMs and BAP measurements are so combined (Celi, 2011a). Cows were milked twice a day and milk yields were recorded daily for individual cows.

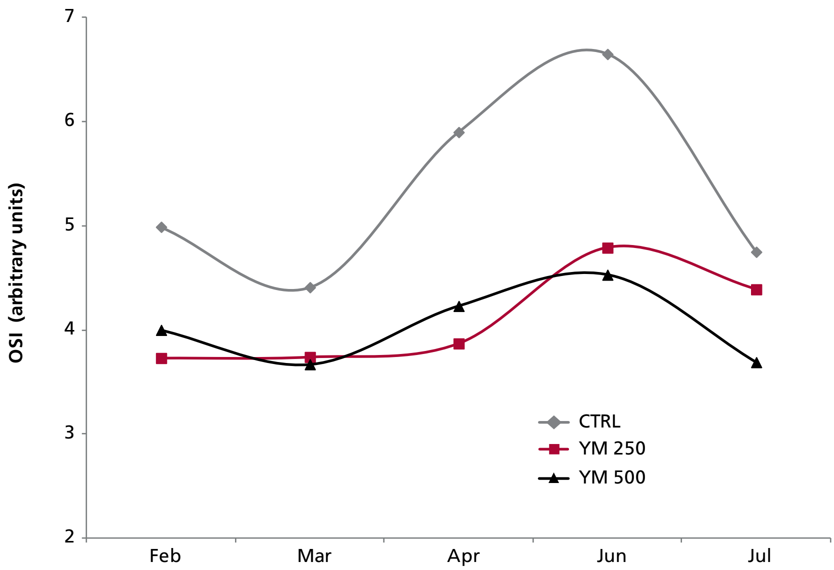
In experiment 1, milk yield significantly decreased over time ($P<0.001$) in both groups; the yield of yerba mate cows was significantly higher ($P<0.05$) than that observed in the control cows at the end of the trial (23 ± 0.3 and 21 ± 0.3 L/cow/day). A significant effect of the interaction time of sampling x diet ($P<0.05$) was noted on cows' LW; indeed yerba mate cows were significantly lighter than the control cows at Week 3. No effect of either treatment or time was noted on BCS. Plasma concentrations of ROMs and BAP were not affected by yerba mate supplementation; however, a significant effect of time ($P<0.001$) was noted. ROMs levels significantly increased after the cows received silage in their diet and then returned to baseline levels at the end of the trial. Plasma concentrations of BAP decreased ($P<0.001$) after silage was introduced into the diet. A significant effect of the interaction time of sampling x diet ($P<0.05$) was noted on plasma AOPP concentration, with yerba mate cows presenting significantly higher levels than the control cows at Week 3.

In experiment 2, daily milk yield averaged 28 ± 0.4, 29 ± 0.5 and 30 ± 0.5 L/cow/day in the control, YM 250 g and YM 500 g groups respectively. A significant effect of the interaction time of sampling × diet ($P<0.01$) was noted on milk yield with the YM 500 g cows having higher yields than the control cows in August and September. Plasma concentrations of ROMs, BAP, and AOPP were not affected by yerba mate supplementation, although a significant effect of time ($P<0.001$) was noted. Both ROMs and AOPP concentrations significantly increased over time. A significant effect of the interaction time of sampling × diet ($P<0.05$) was noted on OSI, with both YM groups presenting significantly lower levels than the control cows in April and June (Figure 1).

Oxidative stress is an active field of research in veterinary and animal science and has been implicated in numerous disease processes, and its biomarkers (oxidants and antioxidants) are considered as new and reliable indicators of animal welfare; indeed, stress of any origin can deplete the body's antioxidant resources (Sconberg *et al.*, 1993). The data gathered in this study suggest that YM supplementation resulted in lower degree of oxidative stress and thus improved welfare.

Information is steadily growing in the field of oxidative stress in animal science, indicating the general importance of oxidative stress and related inflammation disorders to ruminant health and production. There is an increasing need to translate this knowledge into practical applications for animal and veterinary scientists. To help accelerate practical application, we propose the development of an oxidative stress index as an approach in ruminant medicine.

FIGURE 1
Effect of yerba mate supplementation on oxidative stress in dairy cows



Note: Control = grey line; YM 250 g = red line; YM 500 g = black line. OSI (oxidative stress index) represents the degree of oxidative stress and was calculated as follows: ROMs/BAP *100 = OSI, (Celi, 2011a).

The observed increase in milk production suggests that the increased productive performance of these cows might have been due to increased efficiency of feed utilization owing to the presence of tannins in the diet, which increased post-ruminal protein availability. Yerba mate is rich in hydrolysable tannins (Heck and de Mejia, 2007; Bracesco *et al*., 2011) and has very little condensed tannins (0.1 percent/kg DM). Tannins can have both adverse and beneficial effects in ruminants and the inclusion of moderate concentrations of tannins in the diet improves wool growth, weight gain, milk yield and ovulation rate. The inclusion in the diet of moderate levels of tannins can also stimulate feed intake. Given that equal amounts of silage and concentrates were fed to both groups, and that the availability of pasture was limited, the most likely explanation for the increased milk yield is that tannins often decrease the proportion of rumen degradable protein, thereby increasing the dietary protein that bypasses the rumen, which is then available for production purposes.

The increase in milk yield might be also associated with the ruminal effects of the yerba mate. Improvements in milk yield and organic matter digestibility have also been reported after antioxidant supplementation (Smith *et al.*, 2002), suggesting an antioxidant effect on rumen fermentation. Yerba mate is known to possess a strong antioxidant capacity due to its high concentration of polyphenols and caffeoyl derivatives, and its supplementation might thus have had a similar effect. The sharp decrease in plasma total antioxidant capacity (BAP test) and increase in oxidative stress markers (ROMs and AOPP) observed after the cows were fed with maize silage and the positive correlation found between BAP and milk yield (r = 0.33; P<0.001) support this hypothesis.

Finally, the negative correlation that was found between AOPP and milk yield in the non-supplemented group ($r = -0.42$; $P<0.001$), further supports the hypothesis that oxidative stress may be involved in some relevant physiological functions such as milk yield. It is also important to consider that the concentration of phenolic moieties in yerba mate leaves might be affected by the place and year of production and therefore in order to obtain reproducible effects it is important to assess the chemical composition of the yerba mate leaves.

Because yerba mate also contains caffeine, we could also argue that caffeine might have contributed to the observed increase in milk yield. Caffeine has been demonstrated to increase mammary gland development and milk yield (Li and Hacker, 1995). The increase in mammary gland parenchymal tissue after caffeine administration might have been due to an increase in cell size and a relative increase in cell numbers, suggesting an increased secretory capacity of the mammary gland.

The 100-day in-calf rate was 25 percent, 50 percent and 57 percent in the control, YM 250 g and YM 500 g groups respectively. This finding is of extreme importance if we consider the economic benefits of the observed increase in pregnancy rate. According to the economics benefit models provided in 'The InCalf Book for Dairy Farmers' (Larcombe, 2003), a one percent increase in 100-day in-calf rate results in US$590/100 cows profit per year. Given that the 100-day in-calf rate was 25 to 32 percent higher in the yerba mate supplemented cows, this corresponds to a profit of US$14 750–18 880/100 cows.

Increased reproductive performance can affect herd profitability in a number of ways. In first instance, herd average milk yield per day can be increased because cows that become pregnant sooner will have higher milk yields per day of lactation and per year. Also, dry period feed costs are reduced through less prolonged dry periods which are a common feature of delays in conception. In addition, additional increased reproductive performance can increase farmers' profits by decreasing semen costs and increasing number of calves sold annually (Larcombe, 2003). The yerba mate used in this study cost US$2/kg, therefore the overall cost to feed 100 cows for 28 days would have been US$1 400 and US$2 800 for the YM 250 g and YM 500 g groups respectively, yielding a net profit of US$ 12 000–16 000/100 cows.

Future studies should investigate the use green tea waste or other agricultural by-products rich in polyphenols, tannins and antioxidants as a cheaper alternative to products normally used for human consumption. This would increase farmers' profits even further.

CONCLUSION

Our studies indicate that supplementation of dairy cows' diet with yerba mate during mid-lactation and the dry period seems to improve milk yield, cow welfare and fertility. The observation that AOPP concentration significantly increased after the cows were fed maize silage is highly relevant because a high level of AOPP could indicate the presence of an inflammatory process which can compromise correct embryonic development in dairy cows (Celi *et al*., 2011).

The study of the environmental and nutritional factors that affect the oxidative status in ruminants is an interesting area of research and there is a growing body of evidence underpinning the pathophysiological consequences of oxidative stress in farm animals.

Although oxidative stress has been associated with numerous conditions, much remains to be discovered about its role in ruminant health and production. Clarity of understanding of the pathophysiology of oxidative stress in ruminants will make it possible to design specific antioxidant interventions.

The availability and efficient use of the feed resources are the primary drivers of animal performance. Feed security is essential to maximize productivity. Several agricultural and industrial by-products and forest products have been tested as potential sources of feeds for livestock and tea waste is one of them. The by-product from tea leaf, otherwise known as spent tea leaf, may be used as an alternative feed resource for ruminants.

Considering the large-scale production of yerba mate in South America, green tea in Australia and worldwide (Asia and Africa – especially in developing countries) and the availability of its waste (spent tea leaves), it is clear that there is a great opportunity to make intensive use of the available biomass from agro-industrial by-products (spent tea leaves) and other non-conventional feed resources (yerba mate and green tea).

There are many companies using the tea leaves for production of coffee, tea and other drinks. They produce large quantities of chaff, which is often burnt. Apart from losing the economic value of the waste, a huge amount of capital is expended in disposing it. In some places, the waste might constitute an environmental hazard through indiscriminate dumping and incineration.

However, the by-product could be utilized by ruminants, which are capable of converting fibrous feed into human edible food in the form of milk and meat. By converting tea waste products into animal feed, farmers can utilize resources not used in the production process and promote environmental conservation and a recycling-friendly livestock industry. Therefore, the use of alternative feedstuff like green tea, in dairy nutrition represents a novel management procedure that increases farms profits and is extremely easy to use.

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Increasing profit in free-range poultry production systems through improved welfare – the use of nutritional interventions

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MAIN MESSAGES

- Improperly managed behaviour in hens flock brings stress to birds, increases dietary energy and nutrient requirements, and reduces the profitability of producers.
- Nutritional interventions such as dietary protein supply can reduce stressful behaviour by supplying required amino acids, whereas dietary fibre reduces aggression in flock by altering time-budget for aggressive activities.
- Studies presented here indicate that nutritional interventions which reduce aggressive behaviour in hens increase hen-day production and liveability of hens by at least 10 percent.
- Conservative calculations based on current market prices indicate that the dietary interventions presented here can increase profitability in hen flock by at least 20 percent; consequently, such nutritional interventions should be considered when formulating policies for guiding free-range hen raising.

ACRONYMS

HDP hen-day production

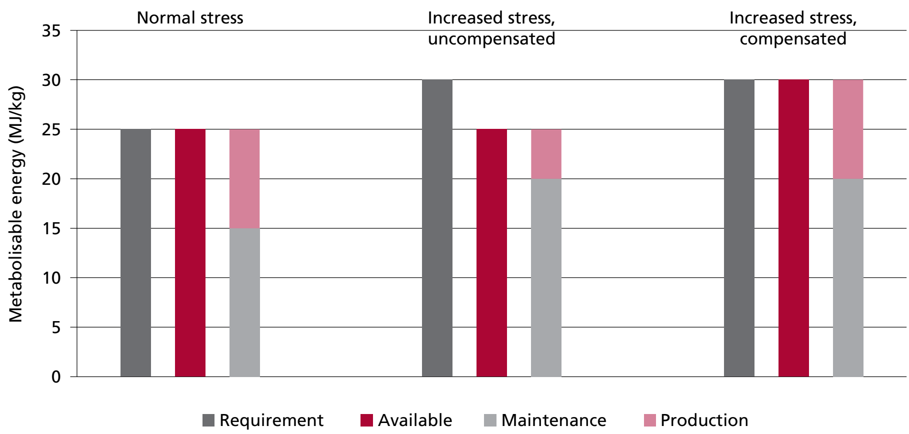
INTRODUCTION

The close relationship between bird welfare and productivity lies in the fact that birds require energy for activities that they perform. Because of the constraint of the energy budget, the energy (ultimately coming from the diet) could be diverted to useful (production) or wasteful (stress avoidance or coping) activities. Birds exposed to poorer welfare will use more of their dietary energy to cope with their stressful condition and ultimately have less energy for productive purposes. Because of the increased activities in free-range chickens (Lomu *et al*., 2004), there is also an increased demand for dietary energy, which will need to be met either through provision of extra dietary energy or by the bird diverting some of the energy away from productive purposes.

It must be recognized that because no production system is stress-free, the feasible objective is to reduce stressors to the barest minimum. This is because there is a positive linear relationship between daily energy expenditure and daily metabolizable energy intake as has been demonstrated in captive birds (Sedinger *et al*., 1992). The impact of stress on maintenance requirement and production is well illustrated in Figure 1 below in which three scenarios of normal stress, increased stress uncompensated, and increased stress compensated situations are presented. The compensation for stress, as shown in scenario 3, is the provision of additional dietary energy to meet increased demand. In both scenarios 2 and 3, profit margin to the farmer is reduced either because of low productivity of the birds (scenario 2) or because of increased feed cost (scenario 3), especially because feed alone can account for more than 60 percent of the total cost of production. Consequently, there are both economic and ethical incentives to improve welfare of chickens in free-range systems.

It is common knowledge that productivity can be enhanced through nutritional interventions but nutrition can also influence bird behaviour. Clearly there are many nutritional approaches that can be used to beneficially modify behaviour but two approaches related to the use of protein and dietary fibre are presented here.

FIGURE 1
Scenarios depicting the effect of increased energy/nutrient requirement on partitioning of energy



Note: The scenarios refer to the partitioning of energy to maintenance and production purpose and consequent influence on total variable cost of production and profit margin in a) when the production is under normal stress condition; b) an increased-stress uncompensated condition and c) increased-stress but compensated condition.

REDUCING FEATHER PECKING BY MODIFYING DIETARY CRUDE PROTEIN LEVEL AND SOURCE

An increasing number of eggs produced for consumption are from free-range hens and there are markets for free-range broiler chickens as well as for organic chickens. It is a requirement for free-range birds produced in the European Community that the outdoor to which the birds have access to be covered with mainly vegetation. This requirement for free-range poultry presents a nutrition problem because poultry nutrition is a precise science and dietary supply must closely match nutrient requirement.

On the other hand, exposure of birds to the free range is fraught with many unknowns. Some of these are related to the knowledge deficit of the exact contribution of pasture to nutrient intake as well as the nutritive quality of the pasture itself. However, it is known that when birds are introduced to the pasture, a considerable portion of their menu includes vegetation which may offer very little nutrient, except fibre and some vitamins. Although the birds may supplement their protein intake by consumption of insects, it may be difficult to ascertain that the birds have received adequate quantity of high-quality protein especially if the use of animal protein in diet is prohibited.

This may be one of the reasons why feather pecking and associated cannibalism are very likely to occur in free-range hens. Effects of dietary protein on feather pecking behaviour may be due to inadequate supply of protein or specific amino acids, or may depend on the type of protein fed. Inadequate protein supply or provision of low-quality protein is a real possibility when birds are fed low-protein diet or exclusively vegetable proteins. Protein deficiency is closely associated with increased feather pecking behaviour (Ambrossen and Petersen, 1997) and birds receiving lower protein than required have greater feather pecking mortality than those receiving higher dietary protein. In addition, birds receiving inadequate amino acids in their diets may have poor plumage development which will encourage feather pecking. In fact, greater feather pecking and associated mortality have been observed in diets with suboptimal amino acids supply (Van Krimpen *et al*., 2005).

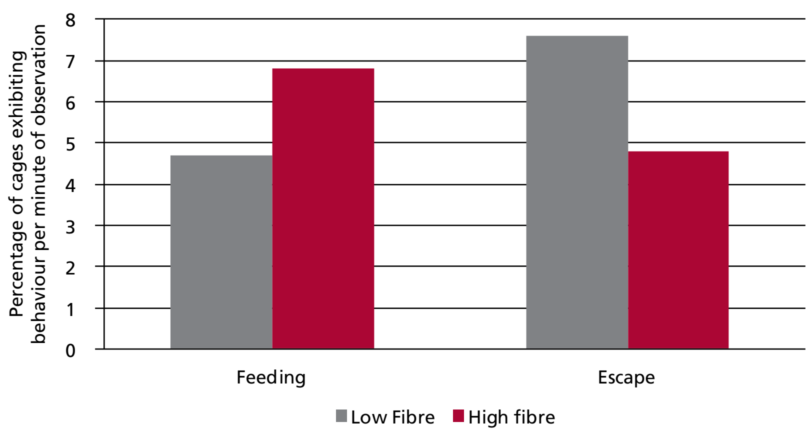
Although practical evidence indicates that feeding of exclusively vegetable proteins may increase the incidence of feather pecking, there is little empirical evidence. One study (Richter and Hartung, 2003) indicated greater incidence of feather pecking related mortality in hens receiving vegetable protein than in those receiving animal protein. Other studies either reported no differences in production or behaviour, or differences in behaviour but not in production. McKeegan *et al.* (2001) observed that pullets receiving plant protein had greater incidence of vigorous pecks and pulls compared with those receiving fish meal although this was not associated with reduced productivity. Evidently, the inconsistencies in feather pecking behaviour and production responses in hens when fed different types or levels of dietary protein can be attributed to many factors including the genetics of the birds, diet type and experimental conditions. Nevertheless, the studies provide compelling evidence that feather pecking behaviour can be influenced or reduced in hens especially by dietary protein supply.

DIETARY FIBRE INFLUENCES PECKING BEHAVIOUR

Esmail (1997) showed a direct relationship between dietary fibre content and incidence of feather pecking and associated mortality. Generally, the incidence of feather pecking decreases with an increase in the level of dietary fibre. The insoluble fibre type appears to play an especially important role in indirectly modifying birds' behaviour. Insoluble fibres are nutrient diluents. They contribute little nutrition to the bird but encourage more rapid gut fill because of their bulky nature. Consequently when birds consume diets that are high in insoluble fibres, they spend more time eating and hence less time on the vice of feather pecking. Huber-Eicher and Wechsler (1998) showed that birds that spent more time foraging spent less time pecking other birds. Hartini *et al.* (2002) showed that dietary indigestible fibre decreased feather pecking and cannibalism in laying hens which suggests that dietary fibres may be an important dietary intervention to address feather pecking behaviour. In their report, Hartini *et al*. (2003) demonstrated that feeding high-fibre diets to laying hens decreased the incidence of "escapes" and increased feeding activity (Figure 2).

Although there may be no simple explanation for how fibre inclusion in the diet influences behaviour, it is conceivable that because birds must balance their dietary needs with nutrient-diluting effect of fibre, a high level of fibre in the diet will consequently force the bird to spend more time eating in order to satisfy its energy need. Mortality, mostly related to feather pecking, has been shown to be lower in laying hens presented with diets containing high level of dietary fibre. It is possible to mix provision of more fibre with supply of adequate protein because the animal will eat to satisfy its requirement. Nevertheless, the need for fibre must be balanced with making sure that the requirement for other nutrients is met in order to ensure that production does not suffer.

FIGURE 2
Influence of dietary fibre on behaviour of laying hens



Source: Adapted from Hartini *et al.* (2003).

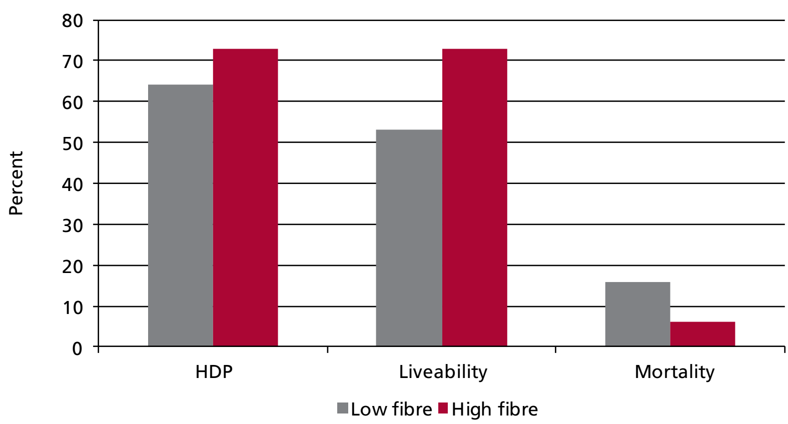
HOW NUTRITIONAL STRATEGIES IMPROVE PROFITABILITY

As indicated previously, poor welfare imposes metabolic demands on animals and promotes a shifting away of dietary energy to compensate for stress rather than production. For example, Glatz (2001) noted that hens with poor feather score (one of the results of aggressive feather pecking) consumed 16 percent more feed and had poorer egg production.

In a series of studies, Hartini *et al*. (2003) showed how dietary fibre influences performance of laying hens. Figure 3 shows that mortality was reduced and liveability increased in laying hen on high-fibre diet and higher hen-day production (HDP) was observed on the high-fibre diet.

Clearly, increased liveability (decreased mortality) and HDP are indicative of a more profitable enterprise. On the basis of the observations on effect of behaviour on performance of laying hens, four scenarios are presented below to depict, in simple terms, how feather pecking and associated cannibalism affect the profitability of a free-range egg-laying operation. Here, a free-range operation with 300 laying hens has been assumed. The costs and returns are based on current market prices. Four of many possible scenarios are presented. Scenario 1 is an operation with adequate welfare and hence no dietary intervention to control feather pecking because, presumably, this has not been an issue on the farm. In scenario 1, there is a somewhat healthy profit margin. In scenario 2, feather pecking has resulted in poor feathering in some of the birds and has become a noticeable problem. However, this has not resulted in reduced production although it has produced an increase in feed cost. Because of the increased feed cost alone, the profit margin is reduced by 18 percent.

FIGURE 3
Performance of laying hens receiving high- or low-fibre diet



Source: Adapted from Hartini *et al.* (2003).

If on the other hand, as depicted in scenario 3, the feather pecking is associated with both increased feed cost and mortality, as is usually the case, the proceeds from egg sales plummet and, even though it is assumed that the labour costs have reduced because of having fewer birds, the profit will drop to 57 percent relative to scenario 1. Scenario 4 is that in which nutritional strategies have successfully decreased feed consumption by five percent (relative to scenario 1) and modestly increased egg production by two percent (relative to scenario 1), and consequently increased the profit by 20 percent relative to scenario 1.

The economics presented above show how the previously discussed nutritional strategies can increase the profitability of a free-range egg laying operation. The increased profit is derived largely from a slight reduction in feed consumption, which is by far the major contributor to the total cost of production. As shown in Figure 1, when any factor reduces the welfare in the flock, the nutritional requirement increases, and the increase is met either by increased nutrient intake or decreased production. In each case, there is an increase in the cost of production and by extension a reduction in the profit and hence there are incentives to reduce the cost of production in order to make free-range production more profitable.

CONCLUSION

Admittedly the causes of feather pecking in hens are many and it can be expected that it will take more than one intervention to address the issue. Nevertheless, there is no doubt that nutritional factors are important when addressing the problem. The importance of the nature and level of dietary protein as well as provision of dietary fibre to address feather pecking have been presented here. How these dietary factors help address feather pecking problem is not completely understood but there are reasons to believe that there are

TABLE 1
Impact of feather pecking and nutritional intervention in a free-range egg laying operation on production costs and profits (all values are in US$)

Scenarios	1	2	3	4
Purchase cost (birds)	2 400.0	2 400.0	2 400.0	2 400.0
Housing cost	66.3	66.3	66.3	66.3
Feeding	6 825.6	7 508.8	7 508.8	6 484.8
Consumables	907.2	907.2	907.2	907.2
Labour	4 000.0	4 000.0	3 680.0	4 000.0
Total costs	14 155.9	10 882.3	10 882.3	9 858.3
Proceeds from eggs	17 952.0	17 952.0	16 156.8	18 360.0
Profit	3 752.0	3 068.8	1 595.2	4 500.8

Note: Most of the costs and returns are based on current market assumptions and are estimated for a free-range operation with 300 birds and an average egg production of 73 percent. Costs for housing, consumables and labour are presented on annual basis. The main product is the egg and the birds have an expected production span of three years. No monetary values have been ascribed to sales of birds or manure.

physiological as well as nutrient- and time-budget aspects to the interventions. Therefore consideration needs to be given to the importance of protein in free-range poultry as well as the types of feedstuff that are used in feed formulation. These nutritional interventions should be part of a good management practices approach to addressing the issue of adequate welfare in free-range poultry.

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Improving animal welfare and economic sustainability in bull-fattening systems in France: A comparison of three different feeding programmes

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MAIN MESSAGES

- The feeding of late-maturing young bulls on a high concentrate diet needs adjustment both of feeding behaviour and adaptation of the rumen microbial ecosystem; a key to success is to avoid feed competition between animals with *ad libitum* feeding.
- Maize silage diet shows a clear increase of intake along the finishing period without apparent digestive disorder and leads to efficient growth; this diet is the most appropriate choice considering both economic gains and welfare of animals.
- Environmental, social and societal assessments of beef feeding should also be taken into account in the sustainability study of beef finishing programmes.

ACRONYMS

CV	coefficient of variation
C (diet)	concentrates (diet)
H (diet)	hay (diet)
MS (diet)	maize silage (diet)
DM	dry matter
DMI	dry matter intake
LW	liveweight
NDF	neutral detergent fibre
SE	standard error

INTRODUCTION

Animal welfare is an increasing concern for citizens around the world and farming systems must now take this issue into account. Farm animal welfare can be assessed by a number of measures including: deviations from normal behaviour typical for the species, production level based on expectations from genetic merit and diet, and health status. Farmers recognize the importance of addressing concerns related to animal welfare and desire solutions to animal welfare concerns that do not compromise the economic sustainability of their production system.

Numerous studies have shown the impact of animal management on welfare. For example, in order to promote weight gain during fattening, beef cattle are usually fed high-energy diets that are rich in fermentable carbohydrates but low in effective fibre. These diets increase concentrations of lactate and volatile fatty acids in the rumen which depress ruminal pH (about 5.5 to 5.0) and increase the risk of cows for disorders such as subacute ruminal acidosis, liver abscesses and laminitis.

The interaction between feeding behaviour and rumen function should be considered in addition to diet management to assess risk of ruminal acidosis and thus welfare status (Gonzalez *et al.,* 2012). Subacute acidosis can also contribute to major economic losses for farmers due to treatment of sick animals, reduced productivity and feed efficiency, and increased feed costs. In lactating animals, subacute acidosis can reduce milk production leading to costs estimated at US$1.12/day per cow (Stone, 1999). Nutritional strategies aimed at decreasing acidosis risk in beef-fattening operations would not only improve animal welfare but would also likely benefit the economic sustainability of these production systems.

In this case study, a high-concentrate diet is compared with two other diets characterized by a higher proportion of fibre, through their impact on the welfare of fattening bulls and overall economic profitability of the feeding system. These diets differed by expected animal weight gain, forage-to-concentrate ratio, and by the proportion of feed produced on-farm. Welfare was assessed through indicators of behaviour (activity and feeding behaviour), of digestion (ruminal pH) and of performance (weight gain and carcass yield) of the animals. Economic profitability was calculated as economic margin per animal. Information on the environmental impacts of these three bull-fattening systems is available in Doreau *et al*. (2011) and Nguyen *et al.* (2012).

ANIMALS AND DIETS

Twenty-four 'Blond d'Aquitaine' bulls (267 ± 22 days old and weighing 326 ± 21 kg) were assigned to six group pens of four animals (two pens per fattening diet). Each bull had access to an individual feeding place and free access to drinking water; straw was used for bedding. In the pre-experimental period, the bulls were fed a maize silage and soybean meal diet. Over a two-week feeding transition period, the three experimental diets were introduced gradually, such that by the end of this period cattle were completely transitioned to the new diet.

The three experimental diets were composed of: 8 percent straw - 92 percent concentrate (Diet C), 44 percent hay – 56 percent concentrate (Diet H), and 58 percent maize silage - 42 percent concentrate (Diet MS) on a dry matter (DM) basis. Diets were fed *ad libitum* until animals reached the same average target live weight for slaughter (650 kg). The concentrate mix was composed of ground maize grain and soybean meal. Percentages of starch and neutral detergent fibre (NDF) on a DM basis in the diets were: 44.8 and 19.1 for diet C, 28.9 and 38.4 for diet H, and 31.3 and 36.4 for diet MS. Further details on diet compositions are given in Mialon *et al*. (2008). For diet C, maize was fed *ad libitum* and the bulls had free access to a straw rack. For the other two diets, forage was dispensed *ad libitum* and concentrate was adjusted to achieve the expected age-to-concentrate ratio. These diets correspond to systems representative of three regions of France (Aquitaine, Auvergne and Brittany for diets C, H and MS respectively) that differ in the nature of feeds produced locally and the normal fattening programmes for young bulls.

INDICATORS OF WELFARE

The behaviour of each bull was scanned every 10 minutes from 24-hour video recordings at several stages of the fattening period (Weeks 0, 5, 9 and 14). Individual feed offered and refusals were measured and recorded on five consecutive days per week throughout the experiment to evaluate dry matter intake (DMI). Feeding behaviour was estimated from the electronic gate recordings taken over seven days (24 hours/day) over the same periods. The daily eating time of each bull was estimated as the mean daily time during which its feeding gate was open. A minimum interval of four minutes between feeding events was considered as the criterion for defining a new feeding meal (Mialon *et al*., 2008).

Feed intake. Feed intake increased steadily over the study period (Figure 1); cattle fed diet H had an average intake of 7.8 kg DM per day while cattle on the other two diet types averaged 8.2 kg per day ($P<0.05$). Variation in voluntary feed intake over time was studied as a potential indicator of digestive discomfort. Variability, expressed by the coefficient of variation (CV) of DM, decreased over time among cattle fed the MS diet (Figure 2). For diet H, variability was high at the beginning and end of fattening. For diet C, the variability was higher during the second part of fattening; this increase in variability corresponded with a decrease in DM intake that occurred over a six-week period (Figure 2). Erratic fluctuations in feed intake are often linked to acidosis occurrences. Average variability in feed intake

FIGURE 1
Changes in DM intake according to diet during bull-fattening period

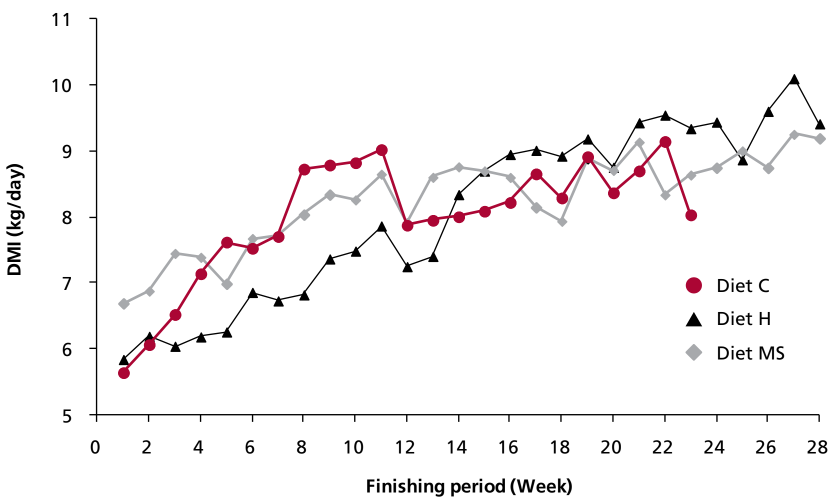
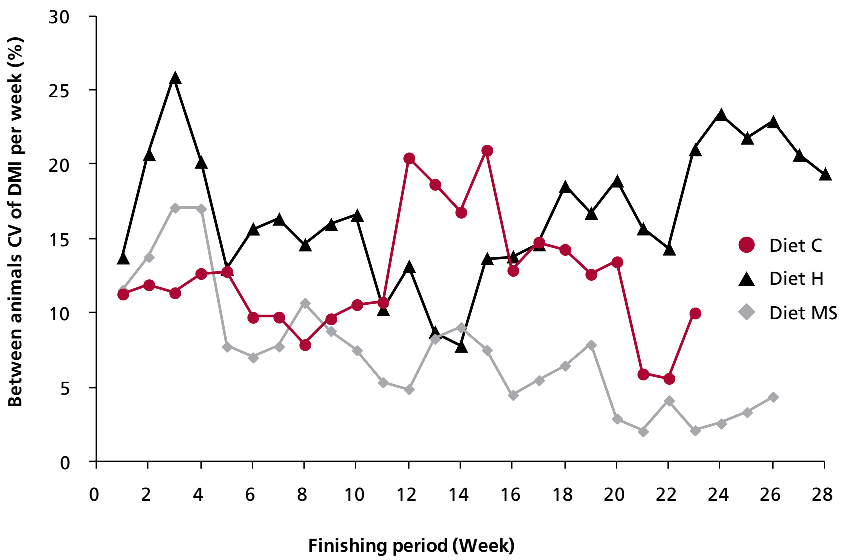


FIGURE 2
Between-animal variability of DM intake according to diet during bull-fattening period

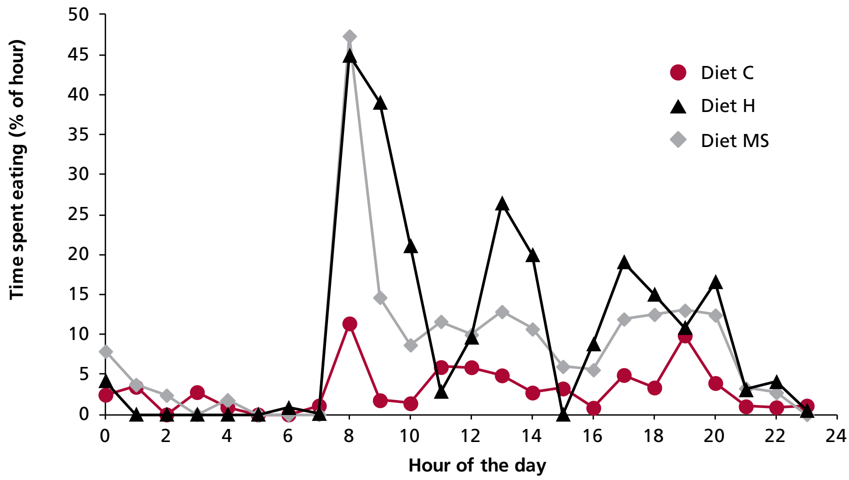


across the entire dietary treatment period was lower ($P<0.05$) for cattle fed the MS diet (CV = 8.6 percent) than for the other two dietary treatments (CV = 13.2 and 15.4 percent for diets C and H respectively).

Feeding behaviour. The forage-concentrate ratio of the diet influenced only those activities directly linked to feeding, i.e. eating and drinking. Bulls fed diet C spent less time eating than the other bulls (47 minutes compared with 135 minutes and 147 minutes for diets C, MS and H respectively, $P<0.05$) and had shorter meals (7 minutes compared with 15 minutes and 20 minutes for diets C, MS and H respectively, $P<0.05$). Over the fattening period, bulls fed diet C decreased their number of meals (data not shown) and spread them over the entire day, while there appeared to be a greater peak in feeding activity following the morning feeding for bulls fed diets H and MS (Figure 3). Rate of intake varied between diets; bulls fed diet H had an average intake rate of 54 g dry matter (DM)/minute, while bulls fed MS and C had average feeding rates of 62 g DM/minute and 173 g DM/minute respectively ($P<0.05$). These results may suggest that animals fed *ad libitum* high-concentrate diets organize their feeding pattern into several meals throughout the day as a strategy for avoiding digestive disturbances (acidosis) associated with consuming large quantities of highly fermentable feed.

Bulls fed diet C spent more time drinking than bulls fed the other diets (27.4 minutes compared with 15.8 minutes and 17.3 minutes for diets C, H and MS respectively, $P<0.05$). It is hypothesized that animals drink more with high-concentrate diets in order to regulate buffering capacity and osmotic pressure in the rumen, factors important for maintaining rumen health.

FIGURE 3
Diurnal pattern of eating activity on Week 14 of fattening according to diet



Source: Mialon *et al.* (2008); reproduced with permission.

In conclusion, young bulls modified both feeding and drinking behaviour in order to adapt to the high concentrate diet C; these behavioural changes probably helped to reduce their risk of developing ruminal acidosis. Modification of feeding behaviour by spreading meals more throughout the day, however, was not enough to ensure optimal digestion because concentrate intake decreased and was highly variable between cattle for a period of time half way through the fattening process.

Ruminal pH as a criterion of digestive discomfort (Gonzalez *et al.,* 2012). Ruminal pH was determined from a ruminal fluid sample collected by rumenocentesis, four to five hours after morning feeding, once weekly at several stages of the fattening period (Weeks 0, 2, 6 and 11 days and one day before slaughter; Figure 4). The rumen pH of cattle was significantly different (P<0.05) between dietary treatments during the first month of the fattening period (5.5, 5.8 and 6.1 for cattle fed diets C, H and MS respectively). After the first month, rumen pH did not differ between diets (average pH = 5.7). These results suggest that, under these experimental conditions, risk of acidosis is highest during the first month of a high-concentrate feeding programme for fattening. The low fibre content of diet C and faster intake rates are likely to have required less mastication of the feed which may have resulted in lower saliva production in cattle eating this diet; saliva is an important buffer of organic acids produced in the rumen during carbohydrate fermentation and insufficient saliva production may have contributed to lower rumen pH. However, no cows in this trial developed clinical acidosis; this may have been due to the dispersion of meals throughout the day. Overall, these results suggest that in parallel to the behavioural adaptation, there is also an adaptation of the rumen microbial ecosystem to high-concentrate diets, but this adaptation takes at least one month.

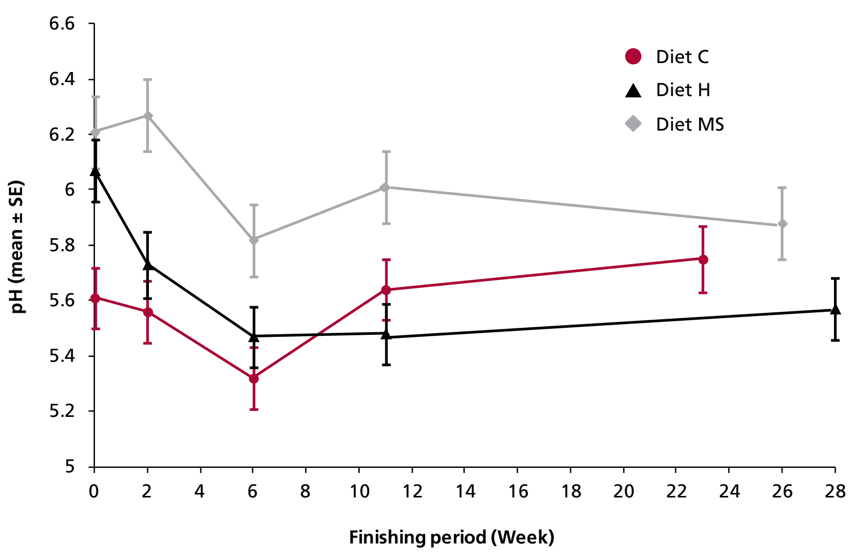
LIVE WEIGHT GAIN

Due to differences in live weight (LW) gain, the fattening period lasted 138, 181 and 155 days for diets C, H and MS, respectively. The average daily gain during the fattening period (for the same final live weight of 650 kg) was 1 860 ± 285, 1 490 ± 120 and 1 710 ± 150 g per day for diets C, H and MS respectively (P<0.05; Micol *et al.*, 2007). These values were beyond the expected live weight gain from French feeding tables for all diets (1 800, 1 350 and 1 600 g/day for diets C, H and MS respectively), suggesting that reduced rumen pH levels observed in cattle fed diet C did not impair weight gain. This may be due to the higher growth rate of the Blond d'Aquitaine breed, because French feeding tables are based on data from other French beef breeds (Charolais, Salers, Limousin, etc.). However, the higher variability of average daily gain for diet C (CV = 15.3 percent compared with eight percent for H and 8.8 percent for MS respectively) may have been a consequence of digestive disturbances in some animals fed this diet.

Hot carcass weights were similar across diets (427, 413 and 426 kg for diets C, H and MS respectively, P>0.05). Carcass yield expressed by kg live weight was lower for diet H than for diets MS and C (63.1, 65.2 and 66.0 percent respectively, P<0.05) but this difference was attributed to a higher digestive content in cattle fed diet H; after correcting for this effect, carcass yield was no longer different among treatments. Carcass fat was higher in cattle fed diet MS relative to those fed diet H, while diet C was intermediate (48, 36 and 41 kg respectively, P<0.05).

In our experiment, modulation of feeding behaviour and adaptation of ruminal microbial ecosystem led to quite high growth performance with diet C. In this study, animals were housed in small groups and therefore the lack of competition for feed may have

FIGURE 4
Time course of ruminal pH according to diet during bull-fattening period



Source: Adapted from Mialon *et al.* (2008).

contributed to this maintenance of growth performance. In general, it is important to pay attention to competition for feed and health problems such as lameness because these factors are known to disturb feeding behaviour and thus may influence the outcome of the type of feeding system used for fattening bulls.

ECONOMIC INDICATORS

Only feed costs were taken into account in this analysis; it was assumed that other costs such as veterinary, rearing, farming and working costs did not depend on the diet. We also ignored the difference in time of building use due to different lengths of the fattening period. The prices of animals were €2.70/kg LW at calf purchase and €3.90/kg carcass sold. Differences in carcass fat did not result in a difference in selling price. For feed costs (Table 1), we considered market prices for concentrate because concentrates were purchased by the farmer. For forage costs, we considered two options: forage was either bought (market price) or produced on the farm (cost price). Since there is no official price for forages, market prices were estimated by experts, except for maize silage where market price was estimated from the market price of grain maize. The cost of forage was based on the costs associated with crop production (seeds, fertilizers, pesticides, sowing and harvest).

The balance (economic margin, i.e., sale of the carcasses minus purchase of calves minus feed cost) was highest for diet MS regardless of which set of assumptions was used (Table 2). With the market price option, the balance was 14 percent and 24 percent higher than for systems C and H respectively. With the cost price option, diets C and H had an equivalent balance, which was one-third lower than the balance for MS.

Due to its high-energy value, use of the MS diet during fattening provides cattle with a readily available energy source without the need to use readily fermentable concentrates, a major risk factor for acidosis. The MS feeding programme not only results in highly productive cattle with efficient growth rates but is also economically profitable. Although the forage component of diet H can be obtained with low input grassland, this diet still required a high amount of concentrate supplementation (814 kg/bull) and was associated with lower growth rates; therefore, this is not an optimal feeding programme. This experiment showed that for the 'Blond d'Aquitaine' breed, diet C is very efficient although expensive due to the high consumption of concentrates (1 021 kg/bull). Overall, the production of maize grain on farm could improve the margin for farmers.

TABLE 1
Feeds prices used in economic results of three bull-fattening systems in France

Feeds	Market price (€/tonne DM)	Cost price (€/tonne DM)
Hay	120	53.50
Maize silage	110	44.36
Straw	100	25.67
Maize grain	212*	-
Soybean meal	408*	-

* *Source:* Agreste (French agricultural database).

TABLE 2
Feed supply and economic margin per bull

	H	MS	C
Live weight at beginning (kg)	*393*	*402*	*404*
Total feed supply (kg DM)			
Forages	646	739	95
Concentrates			
Maize grain	628	310	742
Soybean meal	186	223	279
Carcass weight (kg)	405	417	418
Product (€)	517	543	541
Forage cost (€)(1)	78	81	10
Forage cost (€)(2)	35	33	2
Concentrates cost(1) (€)	209	157	271
Balance(1)(3) (€)	231	305	261
Balance(2)(3) (€)	274	353	268

(1) With market price.
(2) With cost price for forages.
(3) Product (sale of the carcasses of bulls - purchase of calves) – feeds cost (forages + concentrates).

OTHER CONSIDERATIONS

The environmental, social and societal evaluation of diets should also be taken into account. Using an extreme diet such as C reduces greenhouse gases emissions (Doreau *et al.*, 2011) and allows farmers to maximize the growth potential of the 'Blond d'Aquitaine' breed, but it also leads to the ethical debate of whether cereal production should be prioritized for use in animals or humans. Diet based on maize silage leads to a lower energy demand but an increased risk of eutrophication and acidification (Nguyen *et al.*, 2012). A hay diet which results in limited environmental impacts allows for the enhancement of grasslands, and is adapted to regions where grass is the major home-grown feed, as in mountain areas.

In summary, feeding high-concentrate diets in order to maximize growth performance in young bulls may lead to nutritional disorders of digestive origin and result in economic losses for farmers. In this case study, three bull-fattening systems utilizing different diets based on either maize silage (MS), hay (H) or concentrates (C) were compared. Diets differed in their forage-to-concentrate ratio (58/42, 44/56 and 8/92 for MS, H and C respectively). Diet C was associated with the highest live weight gain (1 860 g/day); however, live weight gain and feed intake were more variable with diet C than with the other diets. While on diet C, bulls modified their feeding behaviour by spreading meals throughout the day; this may be evidence of bulls engaging in a feeding strategy aimed at lowering their risk of digestive disorders associated with rapid consumption of a highly digestible feed. Diet H was associated with the lowest weight gain (1 490 g/day) but the economic margin was not different from that of diet C. Bulls adapted better to MS diet than to diets C and H, as demonstrated by less variable intake and live weight gain and higher ruminal pH values.

The economic margin of the MS feeding programme was also one-third higher than the other two feeding programmes. This suggests that good animal welfare and high economic margin are compatible, particularly when using the MS feeding programme.

CONCLUSION

Under the conditions of this case study, diet C resulted in the highest live weight gain thereby allowing for a shorter fattening period. This diet was also found to be more risky for overall health and welfare as demonstrated by lower ruminal pH during the first four weeks of feeding and more variable feed intake. Although diet H does not appear to increase cattle risk of health disorders, performance might have been impaired by the low intake capacity of the breed which contributed to lower average daily gains. The economic margin for farmers is lower for diets H and C than for diet MS. Diet MS thus appears to be the most beneficial option from both an economic and animal welfare perspective. Intake of the highly digestible MS diet increased consistently over the fattening period without cattle demonstrating behavioural or physiological indicators of digestive disorder (acidosis). These results demonstrate that animal welfare and good economic results are compatible.

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Seasonal weight loss – an assessment of losses and implications for animal welfare and production in the tropics: Southern Africa and Western Australia as case studies

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MAIN MESSAGES

- Weight loss has a strong impact on animal productivity compromising the animal welfare and income of farmers worldwide.
- Susceptibility to weight loss may be decreased if indigenous stock, adapted to local conditions, are used and bred towards the increase of their productive traits.
- The molecular study and definition of the molecular mechanisms behind adaptive traits should be the object of research programmes.

ACRONYMS

SWL	seasonal weight loss
WH group	veld hay group
WH+S group	veld hay supplemented group
3MH	trimethylhistidine

INTRODUCTION

Animal production in the tropics is severely limited by several constraints that reduce output and consequently affect productivity and farmers' livelihoods. We have recently reviewed this subject (Lamy *et al.*, 2012) and identified three major categories of production constraints: diseases, parasites and nutritional factors.

Nutritional factors and in particular seasonal weight loss (SWL) are the most relevant of such conditions. Tropical and subtropical climates, including those in the Mediterranean basin, are characterized by the existence of a dry season, during which pasture quality and quantity decrease significantly. In these periods, which are of varied length and regularity, animals frequently lose up to 30 percent of their body weight, with severe consequences to animal productivity as well as welfare parameters because the animals became more susceptible to parasitic and other diseases and ultimately have poorer reproductive performances.

We have studied the physiology of SWL with an emphasis on productive parameters in West Africa (Almeida and Cardoso, 2008), Southern Africa (Almeida *et al*., 2006), and Western Australia (Scanlon *et al.*, 2008; Kilminster *et al*., 2008) during the last 13 years. We have focused particularly on small ruminants – sheep (*Ovis aries*) and goat (*Capra hircus*).

In this document we focus on two case studies, one on goat production traits in South Africa and the second on sheep production parameters in Western Australia. In both cases, special emphasis is given to the impact of SWL on meat and carcass traits. We present such losses from a financial point of view.

STUDIES WITH BOER GOAT BUCKS ON VELD HAY: ASSESSMENT OF LOSSES IN SOUTHERN AFRICA

Southern Africa is one of the regions of the world with the highest susceptibility to SWL. This vast region, encompassing very diverse ecosystems and production systems, extends from Angola, Zambia and Mozambique in the north to the Cape region in South Africa. Over the last two centuries, this region has been strongly associated with extensive ruminant production systems, particularly targeting beef, mutton/wool and karakul productions, frequently for export to international markets. SWL is particularly limiting in the regions bordering the Kalahari Desert. In these regions, comprising Angola, Namibia, Zimbabwe, South Africa and Botswana, rainfall patterns are very irregular and sheep production is a major economic activity for both commercial and subsistence farming systems, whereas goats, traditionally associated with the latter, are in high demand for a growing internal market.

These regions are characterized by a treeless plain, known in South Africa as the *veld,* in which red grass, *Themeda trianda*, is the main grass. During the dry season, red grass has little nutritional value and consequently animal diets have to be supplemented. We have studied the losses caused by the lack of supplementation on the productive (Almeida *et al*., 2006) and reproductive (Almeida *et al*., 2007) parameters for the most important commercial South African goat breed, the Boer goat. This work is particularly relevant due to the growing importance of goats in South Africa, where commercial goat production is rapidly increasing. In this case study, we briefly quantify such losses and relate them to animal welfare. For experimental details, readers are asked to consult the abovementioned references.

Briefly, 15 six-month old Boer goat bucks were de-wormed and, after an adaptation period to experimental conditions during which the animals showed no sign of disease or parasites, were considered to be in good health. The bucks were subsequently divided into two experimental groups, fed on chopped winter veld grass (locally known as veld hay – WH group) and the same hay supplemented with maize, molasses and urea (WH+S group).

The study lasted 29 days, during which the animals were weighed regularly. At the end of this period, the animals were slaughtered in a commercial abattoir and carcass characteristics determined. Results have been published previously (Almeida *et al*., 2006) and demonstrate the very high costs of the lack of supplementation. In fact, animals in the non-supplemented group had roughly 23 kg of live weight compared with the animals in the supplemented group which had a live weight of 31 kg.

Regarding carcass weight, non-supplemented animals had 70 percent of carcass weight compared with the supplemented animals. If we consider the price of US$1.43/kg live weight of the North American market, this means that an animal in the non-supplemented group would be worth roughly US$32, whereas an animal in the supplemented group would be roughly US$45, with an average loss of US$13 per animal. Interestingly, even in the cases of small flocks, the losses would still be considerable (US$130 for 10 animals).

Maize prices are approximately US$200 per tonne and molasses US$0.5 per kg. Animals would consume a daily amount of 170 g of maize meal and 44 g of molasses, respectively US$0.03 and US$0.02, for a total of US$0.05 a day. If we consider an average supplementation season of 90 days, this means that supplementation would have a cost of US$4.5 per animal. Farmers would therefore have a profit of approximately US$40 per animal.

These results demonstrate the importance of supplementation and the losses that are incurred by its absence. Maize, molasses and urea are the most important feedstuffs for supplementation in the tropics. They provide a safer, and nutritionally sound, alternative to other supplements of poor nutritional value such as branches, or of dubious microbiological quality like chicken litter. Additionally, maize, molasses and urea are easy to purchase. Consequentially their use is widespread in Southern Africa and, in the particular area in which this trial was conducted, are often used for cattle and sheep.

With this trial, we also demonstrated the relevance of supplementation for the goat species, in particular the only exclusively-meat production goat breed in the world, the Boer goat. Results of the trial were first planned with and then also made available to commercial farmers in the Central Free State region of South Africa who were shifting or considering shifting to goat production in order to supply the domestic market. Additionally, this trial was made with their support through the donation of the animals used. Ultimately, the practice has since become standard in commercial goat production systems in that region of South Africa.

Animal welfare is rapidly becoming one of the major aspects of animal production on a global scale, not only at the level of the industrialized world, but also in developing countries. In fact, it has been shown that adequate husbandry and management practices, as well as transport and slaughtering conditions, have a major influence on product quality and farmer income, in addition to their obvious benefits to the animal itself and to the perception of animal production.

This trial clearly demonstrated the beneficial effects of supplementation on animal welfare. In fact, it was observed that the animals that were not subjected to nutritional stress displayed a quieter attitude when compared with the animals that were losing weight. Additionally animals not losing weight also displayed a much higher vitality. This has direct repercussions at the reproductive level, with higher testicular development and higher sperm counts (Almeida *et al.*, 2007) for supplemented animals.

Furthermore, we have determined the serum concentrations of several free amino acids from these animals (Almeida *et al.*, 2004) and interestingly we suggested one (3MH or tri-methyl-histidine) that could be used (in goats) as a potential biomarker of nutritional stress. The serum concentrations of 3MH in control animals ranged between 40-60 µmol/L whereas animals subjected to weight loss had serum concentrations of between 150-180 µmol/L. 3MH may therefore be a good biomarker of nutritional status in goats, and applicable to welfare monitoring in this species.

Finally, as expected, the supplemented animals had carcasses with higher energy, fat and protein content, therefore of higher nutritional value to the consumer. This also indicates that these animals might be better prepared to withstand putative parasite or disease challenges, therefore indicating that animal nutrition and welfare are two important aspects of the same issue. This means that relating productive parameters, farmers livelihoods, consumer demands and needs are ultimately of key relevance to the sustainability of animal production systems.

SHEEP ADAPTATION AND NUTRITIONAL STRESS: ASSESSMENT OF LOSSES IN WESTERN AUSTRALIA AND IN BREEDS WITH DIFFERENT GENETIC BACKGROUNDS

Sheep production in Australia has always been based on wool production, with meat as a secondary aspect. Australian production has been based on the Merino breed and sheep are managed in extensive production systems. Recently, for several reasons, such as a drop in wool prices and increase of production costs particularly in shearing, Australian production systems have been shifting to shedding hair sheep such as the Dorper and Damara. These breeds are better suited for the lamb production market, do not need to be shorn and need less input then traditional Merino breeds (Almeida, 2011).

In a nutritional trial that took place in Merredin, Western Australia, we evaluated the growth (Kilminster *et al*., 2008) and carcass traits (Scanlon *et al.*, 2008) of six-month old lambs from the Damara, Dorper and Australian Merino breeds under control (*ad libitum* feeding) and weight loss conditions (80 percent of maintenance needs). A total of 72 animals were used, and each experimental group had 12 ram lambs. Animals were dewormed and, after an adaptation period to experimental conditions in which the animals showed no sign of parasitic or other disease, were considered to be in good health and subsequently divided into six experimental groups (two per breed). Animals were fed on commercial pellets.

The trial lasted a total of 42 days, at the end of which animals were slaughtered and carcass and meat traits determined. Regarding liveweight changes, results are presented in table 1. Animals in the weight-losing diet lost approximately 10-15 percent of their initial weight. Interestingly, the animals of all breeds seem to adapt to the restriction level by day 24 when weight decrease seems to be slower. Our observations suggest that under confined feeding of restricted and control diets and considering the growth parameters, Damara, Dorper and Merino ram lambs perform similarly.

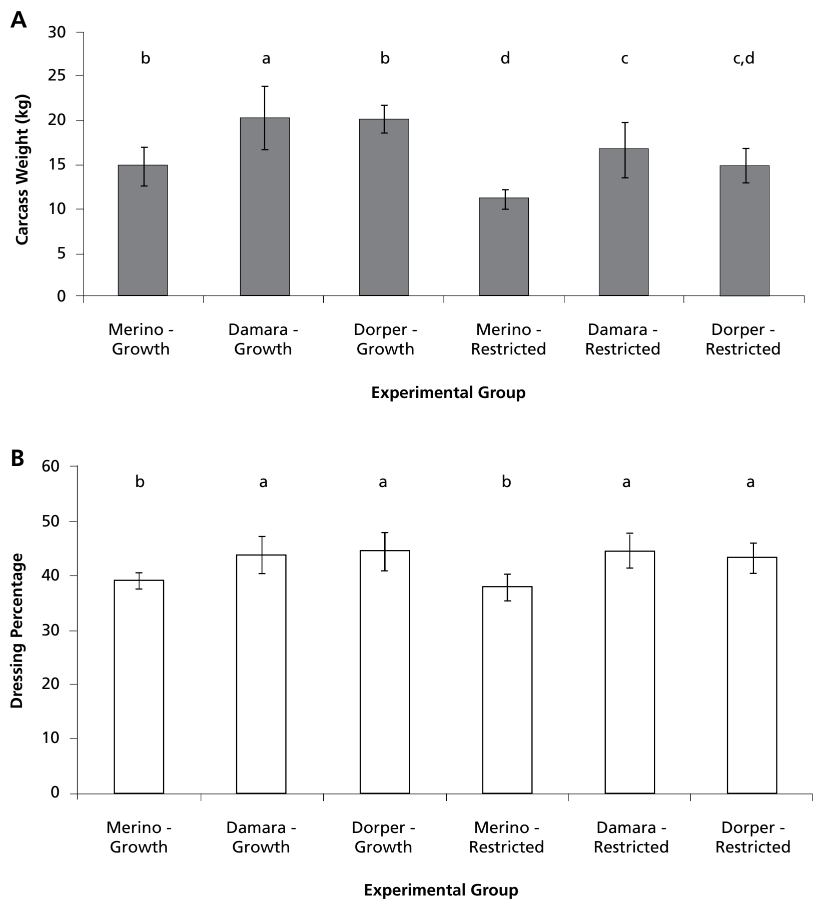
In addition, we have studied the carcass characteristics of the animals of the three breeds (Kilminster *et al.*, 2008). Results for hot carcass weight and dressing percentages are presented in Figure 1. Experimentally induced weight loss seems to lead to a loss of approximately five kg per carcass. In the North American market (www.indexmundi.com), a frozen lamb carcass would fetch an approximate US$2.5 per kg. A gross estimation of the losses caused by weight loss would therefore be in the range of approximately US$12 for a

TABLE 1
Sheep liveweight changes (kg)

	Restricted Feeding Diet			Growth diet		
Day	*Merino*	*Damara*	*Dorper*	*Merino*	*Damara*	*Dorper*
0	32.90 ± 4.9	42.00 ± 7.0	37.90 ± 6.0	34.20 ± 4.4	43.10 ± 7.4	39.50 ± 7.9
14	29.08 ± 3.4	38.18 ± 5.5	34.71 ± 6.1	33.96 ± 4.5	41.95 ± 5.9	39.60 ± 8.4
31	28.60 ± 3.3	36.60 ± 5.3	34.37 ± 5.9	37.90 ± 5.0	42.27 ± 5.7	44.40 ± 7.7
42	28.60 ± 3.1	37.30 ± 5.3	34.30 ± 5.6	37.70 ± 4.5	46.00 ± 5.6	45.00 ± 7.5

Source: Adapted from Scanlon *et al.* (2008).

FIGURE 1
Mean hot carcass weights and dressing percentages of the different groups



Note: Bars with different superscripts indicate significant differences.
Source: Adapted from Kilminster *et al.* (2008).

total carcass value of US$50, i.e. almost one-quarter of the total value. If we extrapolate the losses to a larger scale, it is understandable that weight loss may have a devastating effect on animal production levels and outputs even for small or medium-sized flocks.

Given the interest in the subject of low-care hair sheep breeds, this trial was strongly supported by and discussed with Western Australia's farming community. Consequently, the trial was actively followed by local farmers and the meat industry, either through oral presentations, direct contact between researchers and farmers, or publication in specialized literature with relevance to farmer-oriented publications in Australia. The trial and the subject increased awareness on the importance of sheep supplementation during the dry season, but more importantly on the suitability of shedding-hair sheep to a sheep-producing system where wool is losing importance and where the necessity to lower inputs is rising. Finally, it must be said that the interest in alternative sheep breeds in Australia is rapidly increasing as may be seen from the growing number of animals of the Damara and Dorper breeds (and Merino crosses) that are present in the several Australian states, currently representing eight to ten percent of the total Australian sheep population.

From a welfare perspective, and similar to the Boer goat study described above, it is clear that nutritional status strongly influences animal welfare, not only from strictly nutritional and productive points of view, but also because underfed animals may possibly become more susceptible to disease and parasite challenge, more agitated and difficult to handle. We have also conducted a protein expression analysis at the muscle level, using two-dimensional electrophoresis and protein identification through mass spectrometry (Almeida *et al.*, 2012) in which we have identified one candidate (histidine triad nucleotide-binding protein) that could be considered as a putative candidate of tolerance to SWL and therefore of interest as a nutritional welfare biomarker (Almeida *et al*., 2012). For all these reasons, we believe that adequate nutritional management and supplementation practices are extremely important for limiting the adverse consequences of weight loss because they have implications at several levels: productive performances, farmer's income, product quality and humane and societal perception of animal production.

CONCLUSION

As shown by these two simple and straightforward case studies, weight loss has a strong impact on animal productivity. Additionally, weight losses are accompanied by serious decreases in animal fertility and reproductive ability, as well as an increase in the susceptibility to disease and parasites, ultimately with strong implications for animal health and welfare. This is severely compromising for the income and livelihoods of farmers, particularly in less developed countries, where access to veterinary care and medicines, as well as feed supplements, is virtually non-existent or unaffordable.

Finally, we believe that susceptibility to weight loss may be decreased if indigenous stock, adapted to local conditions, are used and bred towards the increase of their productive traits. The molecular study and definition of the molecular mechanisms behind those adaptive traits should therefore be widely studied. These will be major challenges for animal production in the 21st century, with strong implications for the ways that society and consumers perceive animal production activities.

ACKNOWLEDGEMENTS

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DISCLAIMER

All trials mentioned in this publication were authorized and monitored by the competent veterinary authorities and according to local and European Union legislation.

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Managing the costs of metritis: Using feeding behaviour to facilitate disease detection and improve dairy cattle welfare

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MAIN MESSAGES

- Metritis is associated with reduced 305-day milk yield, increased culling risk and poor reproductive performance.
- Feeding behaviour, dry matter intake (DMI) and social behaviour before calving can be used for the early identification of cows at risk for developing metritis after calving.
- Cows should be monitored closely for behavioural changes, particularly during the two weeks leading up to calving.
- Early detection of disease will hasten prompt treatment and help with the development of alternative management practices that focus on disease prevention, thus improving overall dairy cattle welfare.

ACRONYMS

BT body temperature
DIM days in milk
DMI dry matter intake
DOPN days open
MP multiparous
PP primiparous
PR pregnancy rate

INTRODUCTION

Maintaining healthy animals is a key component of animal welfare. An effective dairy cattle herd health programme is also critical for maintaining herd profitability. Illness can compromise production efficiency by reducing milk production and reproductive performance, and shortening the life expectancy of a dairy cow through increased rates of involuntary culling.

Traditionally, research addressing the health concerns of dairy cattle has focused primarily on aspects of nutrition, physiology and metabolism. Despite these efforts, disease incidence, particularly around the calving period, continues to be high (Table 1). Improved methods for detecting cattle that are at increased risk of becoming sick during this critical period could aid in early treatment and prevent the illness from progressing to its clinical and consequently most costly stage.

When animals are sick they commonly display a variety of symptoms, including changes in body temperature, lethargy and decreased appetite. Early research in our group (Urton *et al.*, 2005), as well as work conducted with fattening beef steers, has shown that changes in feeding behaviour can be used to identify sick animals and even to predict morbidity. These studies, however, did not explore the relationships between intake, behaviour and health during the period around calving in the lactating dairy cow.

This case study focuses on metritis (uterine infection), a common and costly disease affecting dairy cattle during the weeks following calving. Through a series of research studies conducted by our group, we have established a number of lines of evidence indicating that feeding behaviour, including DMI, and social behaviour can be used to identify cows at risk of metritis in the days before calving. More recently, our group investigated the long-term impact of metritis on milk production and culling risk, providing further evidence that metritis is a costly disorder and that overall farm profitability is likely to improve with improvements in early disease detection.

FEEDING BEHAVIOUR AND DMI PREDICT METRITIS

On the average dairy farm, metritis detection occurs only during routine herd health checks by the veterinarian or trained farm staff, which take place every two to three weeks. The weekly or biweekly gaps between health checks results in many early warning signs of metritis going unnoticed until such time as the disease is in its clinical stages. A practical method for continuously monitoring the health status of dairy cows would be extremely useful for producers.

At the University of British Columbia's Dairy Education and Research Center (Agassiz, BC) an automated feeding system (INSENTEC, Marknesse, Holland; Photo 1) was used to continuously record feeding behaviour and intake of 101 Holstein dairy cows from two weeks before until three weeks after calving.

TABLE 1
Lactational incidence rate (mean and range) of selected periparturient health disorders

Disorder	Lactational incidence rate (%)	Range (%)
Milk fever	4.6	0.2 – 8.9
Displaced abomasum	2.1	0.6 – 6.3
Ketosis	4.1	0.2 – 10
Retained placenta	7.8	3.1 – 13
Metritis	10.8	1.7 – 43.8
Mastitis	17.6	2.8 – 39

Source: Data has been adapted from Ingvartsen *et al.* (2003).

Metritis severity was diagnosed on the basis of daily rectal body temperature (BT) as well as condition of vaginal discharge that was assessed every three days after calving until 21 days in milk (DIM). Any cows diagnosed with health disorders other than metritis within 21 DIM were excluded from the study. A total of 62 cows were included in the data analysis: 12 severely metritic cows [five primiparous (PP), seven multiparous (MP)]; 27 mildly metritic cows (12 PP, 15 MP); and 23 healthy cows (five PP, 18 MP). Cows with mild metritis (purulent vaginal discharge with a foul odour and with our without a fever: temperature ≥ 39.5 °C) were clinically diagnosed on average nine days after calving, while those with severe metritis (putrid, watery, red/brown discharge with foul odour and a fever) were clinically diagnosed on average five days after calving.

Cows with severe metritis had lower DMI and spent less time at the feed bunk during the two-week period prior to calving and for nearly three weeks before the observation of clinical signs of infection (Figure 1). Cows with mild metritis also consumed less and tended to spend less time at the feed bunk during the week before calving. During the week before calving, cows were 1.72 times more likely to be diagnosed with severe metritis for every 10 minute decrease in feeding time, and for every 1 kg decrease in DMI during this period, cows were nearly three times more likely to be diagnosed with severe metritis.

Feeding time for all groups of cows was positively correlated with DMI, meaning that cows with longer feeding times also had greater DMI. However, this relationship was strongest in the severely metritic cows. These results provide evidence that sick cows (or cows that will become sick) utilize the time spent at the bunk more efficiently (i.e. when they are at the bunk they spend that time eating).

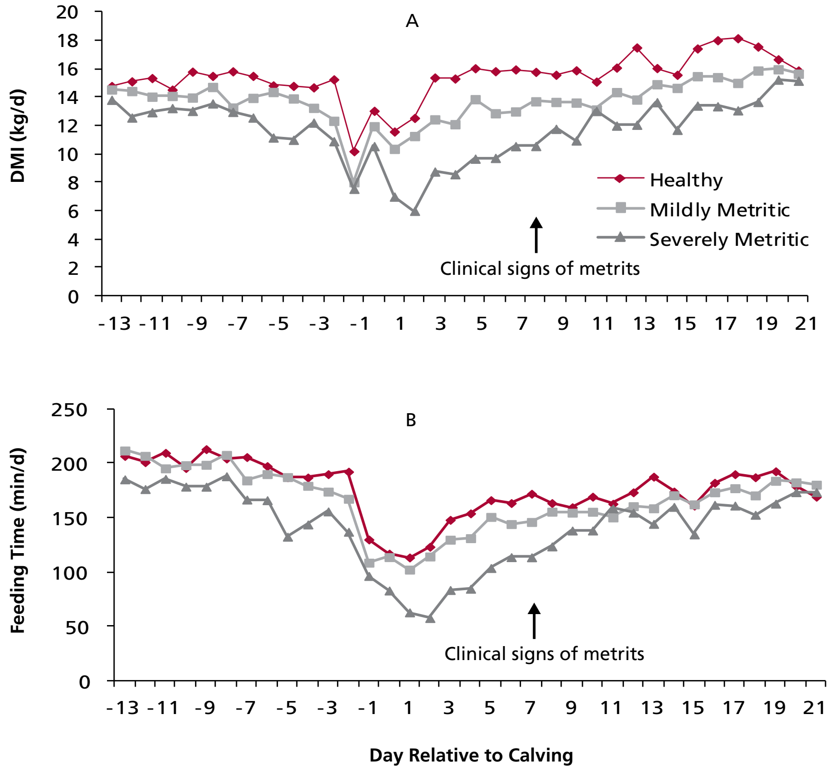
During the week before calving, cows that were later diagnosed with severe metritis also had altered social behaviour as they engaged in fewer aggressive interactions at the feed bunk (i.e. displaced others from the feed bunk less often) and consumed less dry matter compared with cows that stayed healthy during the periods following fresh feed delivery, a time when cows are highly motivated to eat. Cows with severe metritis after calving appeared to be less motivated to compete for access to feed before calving. These results may suggest that these cows are socially subordinate and unwilling to engage in interactions with more dominant individuals.

This research provides evidence that feeding behaviour, DMI and social behaviour before calving can identify cows at risk of developing metritis after calving. Whether a reduction in intake and feeding time before calving is a cause of postpartum infectious disease or is an effect of a pre-existing condition is still to be determined.

Photo 1
The electronic feed monitoring system (INSENTEC) at the University of British Columbia

FIGURE 1

Average daily DMI (kg/day; A) and feeding time (min/day; B) of healthy (n = 23), mildly metritic (n = 27) and severely metritic (n = 12) Holstein dairy cows from 13 days before until 21 days after calving



Source: Re-drawn from Huzzey *et al.* (2007).

EFFECTS OF METRITIS ON MILK YIELD, CULLING RISK AND REPRODUCTIVE PERFORMANCE

To explore the long-term consequence of metritis, data from two of our previous transition cow studies were combined (Huzzey *et al.*, 2007 and Proudfoot *et al.*, 2009). Using only data from multiparous cows, a population of 43 healthy animals (no fever or other clinical signs of disease by 21 days postpartum) and 16 severely metritic animals (see definition above) were identified. Individual DMI was monitored for 21 days after calving for all experimental animals using the INSENTEC electronic feeding system. During this time, cows had *ad libitum* access to both feed and water.

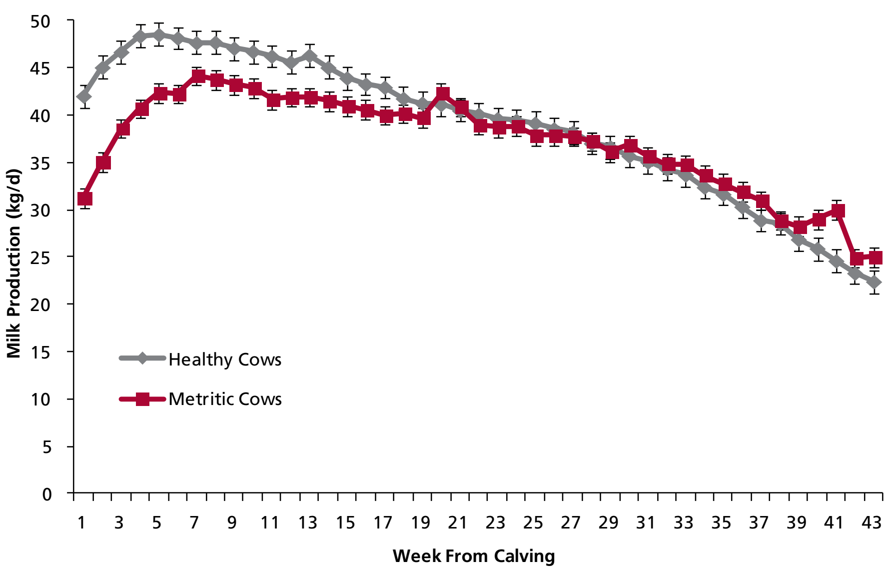
Metritis during early lactation had an overall negative impact on the milk production of multiparous cows. These animals produced less milk than those that remained healthy. This reduction in milk yield was experienced not only during the metritis infection but also throughout the first 20 weeks of lactation, even though all sick cows received veterinary care (Figure 2). Cows with metritis and lower milk yield consumed approximately 3.5 kg/day less DMI during the first 21 days after calving. The reduction in feed intake observed over the first 21 days in lactation for cows with metritis may help to explain the lower daily milk yield observed in these animals over the first 20 weeks of lactation; it remains unknown whether these cows had lower feed intake beyond three weeks after calving.

Multiparous cows with metritis were more likely to be culled than those that remained healthy. In total, eight of the original 16 cows with metritis were culled (50 percent) while only nine of the original 43 healthy cows were culled (20 percent). The odds of being culled were 3.8 times greater for cows with metritis than for healthy cows. Cows that were culled produced less milk than those that were not culled during the first 12 weeks of lactation. Culling decisions were made before any indications of reproductive problems (indeed, most of the culled cows were never bred). The decision to cull was likely driven by a combination of ill health and low production in the first weeks of lactation.

Other researchers have shown metritis to be associated with compromised reproductive performance, as pregnancy rates are 4.5 percent lower for cows with metritis than for cows without metritis (Figure 3; Overton and Fetrow, 2008).

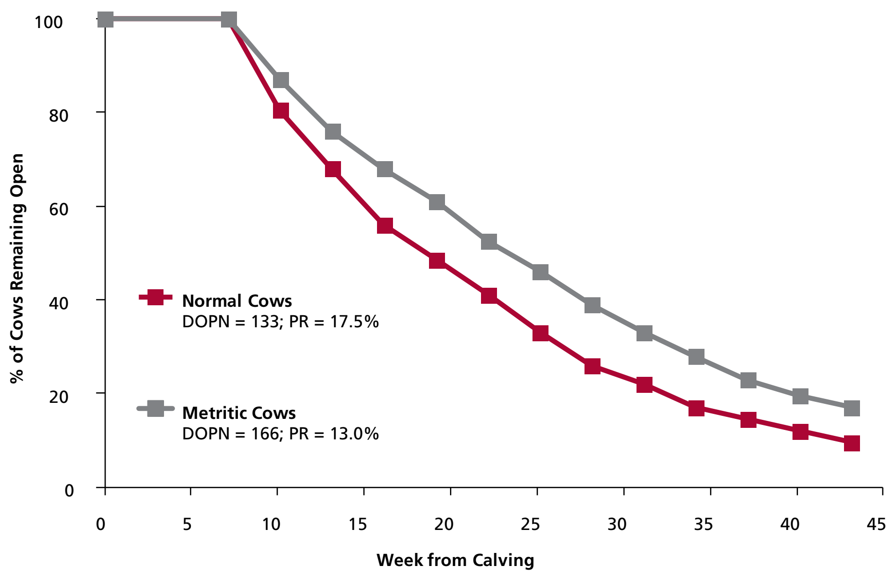
FIGURE 2

Multiparous cows with metritis have lower average daily milk yields throughout the first 20 weeks of lactation compared with healthy multiparous cows



Note: Weekly averages are based on seven days of data.
Source: Figure redrawn from Wittrock *et al.* (2011).

FIGURE 3
Median days open (DOPN) and pregnancy rate (PR) for cows with metritis (grey line) and normal cow (black line)



Source: Redrawn from Overton and Fetrow (2008).

THE ECONOMIC BURDEN OF UTERINE DISEASE

The financial burden associated with metritis comes from both direct and indirect costs. In a study aimed at describing the economic impact of metritis, Overton and Fetrow (2008) identified four key areas where costs are incurred: 1) reduced milk production; 2) increased culling risk; 3) decreased reproductive performance; and 4) additional treatment costs.

Using data collected from 500 cattle diagnosed with metritis (comparable to the severe metritis category in our studies described above) and a series of assumptions (e.g. milk price, salvage value for culled cows, treatment type, etc.; see paper for details), these researchers estimated the following costs as a consequence of metritis:

1. Reduced milk production: US$83/case
2. Increased culling rate: US$85/case
3. Reproductive complications: US$109/case
4. Treatment: US$53–109/case

Using this information, these researchers estimated that costs due to metritis could reach US$330 to US$386 per diagnosed case. To place that cost in the context of the entire dairy operation, if a 1 500-cow dairy herd had a 30 percent metritis incidence rate, the costs associated with metritis could range from US$148 000 to US$174 000 annually.

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Proper feeding improves welfare, calf performance and future productivity of dairy calves

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MAIN MESSAGES

- Adequate nourishment and management early in life not only improve performance, health and welfare of young calves, but also milk production and longevity .
- Attaining improved growth early in life does not represent an extra cost in the total investment in a heifer from birth to first calving, and the benefits are therefore two-fold: less health issues early in life (and thus more welfare), and more milk production combined with equal or even lower raising costs.
- Suggested actions are:
  - Feed six litres of milk or milk replacer during the first two months of life;
  - Provide chopped straw or chopped poor quality hay in addition to a starter;
  - Move calves into groups of eight-ten when milk offer is halved (usually one week before weaning completely);
  - Group young calves into pens of eight-ten animals based on their previous history of bovine respiratory disease.

ACRONYMS

DIM days in milk
BRD bovine respiratory disease

INTRODUCTION

In dairy production, as in any other business, a careful allocation of resources and planning is needed to ensure optimal production in the future. Investment in future milk production starts with the selection of an optimal pool of genes for insemination of a dam that will hopefully transfer the desired genetic potential to the offspring. After conception, the genetic potential is set, but nutrition, management and health are key factors in ensuring that this genetic potential is fully expressed later in life.

Unfortunately, care, nourishment and health of dairy replacements heifers are, in many instances, below a level that could be considered adequate. Producers are focused on the lactating animals and usually place young stock as a lower priority. Heifers are usually held in the oldest barn of the enterprise and receive feeds that producers would rather not feed to lactating cows. In addition, new-born calves are separated from the dam and fed on milk replacers or whole milk (either using a bottle and nipple or a bucket) and offered solid feed to promote early weaning. Providing milk or milk replacers to calves is expensive and labour intensive, and producers are therefore usually eager to wean calves as soon as possible and offer a minimum amount of milk or milk replacer.

This case study provides evidence that good nutrition early in life and adequate management not only improve growth, health and welfare of young stock, but also reduce production costs (in the long run), and result in animals that will be more profitable due to improved production ability and increased longevity.

There are specific time windows during development that have long-lasting consequences on the physiological function of the individual. For instance, the pioneering work of McCance (1962) illustrated that limit-feeding rats during the first 21 days of life resulted in a lifetime programming of growth pattern that was lesser than that of rats fed properly. When the dietary restriction was applied for 21 days but at a more advanced age, the intervention had no lasting effect because the underfed rats showed compensatory growth gains when re-fed at normal levels. Likewise, this case study illustrates how early-life nutrition of calves has consequences for the future milk performance of dairy cows.

WELFARE CONSEQUENCES OF IMPROVING NUTRIENT SUPPLY TO YOUNG CALVES

It is not uncommon to find mortality and morbidity of young calves above ten percent and around 30–50 percent respectively. However, with proper nutrition and management, these figures can be effectively reduced to less than three percent and less than 20 percent respectively. In terms of nutrition, growth (and robustness or resistance to disease) can be improved by providing more nutrients to calves.

Traditionally, producers have been restricting the supply of milk or milk replacer to four litres/day because it is considered expensive. However, four litres/day of milk replacer is, in many situations, insufficient to supply nutrients to ensure adequate immunological function. Thus, an efficient method to reduce morbidity (and improve welfare) is to provide more milk (with an optimum level of six litres/day).

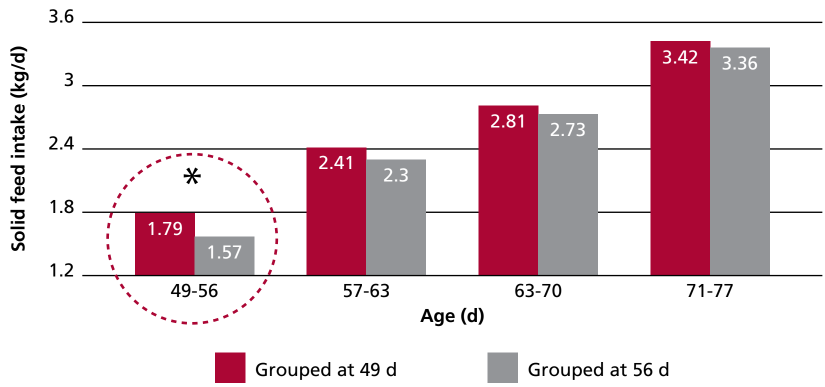
Interestingly, Bach and Ahedo (2008) used a linear programming optimization model and concluded that the entire cost of rearing a heifer (from 0 to 24 months of age) was actually reduced when feeding six rather than four litres/day of milk replacer during the first two months of life. This is because, despite the fact that milk or milk replacer is expensive, the high feed efficiency early in life offsets the apparent increased cost associated with feeding milk replacer. It is true that in the first two months, the nutritional demands of the calf increase, but when calving at similar body weights, heifers that were reared on six litres/day of milk replacer are less expensive to produce than those that received four litres/day because these had to grow at later stages in life at a lower feed conversion efficiency to reach equivalent body weight.

In terms of management, the stress associated with weaning may compromise welfare and the immune response of calves for at least two weeks after weaning and illness may compromise the growth and welfare of calves. Traditionally, it has been suggested to keep calves isolated for one or two weeks after weaning (to avoid commingling animals when suffering weaning stress). However, no research study has demonstrated that this practice is effective. Conversely, Bach *et al.* (2010) showed that grouping calves at pre-weaning, when the milk replacer offered was halved, fostered intake of solid feed (Figure 1) and diminished the number of cases of bovine respiratory disease (Figure 2) compared with calves that were kept individually housed. Thus, this management strategy would clearly improve the welfare of young calves.

Group composition at weaning is also important because grouping animals based on the history of respiratory disease will minimize subsequent incidence of the disease. Research has shown (Bach *et al.*, 2011) that by forming a group of animals that have had a previous respiratory case while individually housed will allow the rest of animals to suffer less respiratory illness and improve performance (Figure 3).

FIGURE 1

Solid feed intake increases when calves were commingled at pre-weaning (milk replacer reduced by half at 49 days of age) compared with calves kept individually



* indicates significant differences at *P*<0.05

FIGURE 2

The number of respiratory cases incurred by calves decreases when calves are grouped at pre-weaning (when milk replacer is reduced by half at 49 days of age)

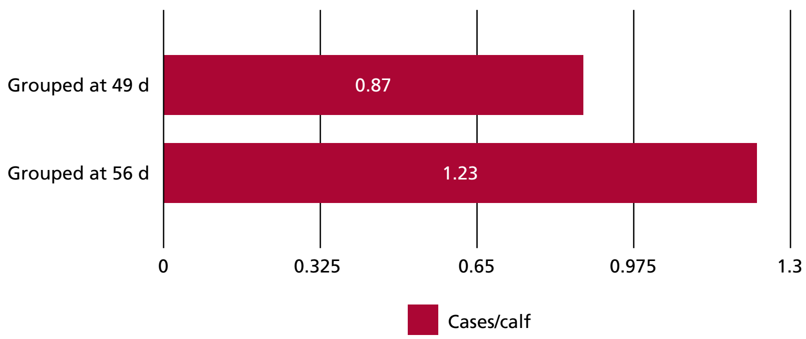
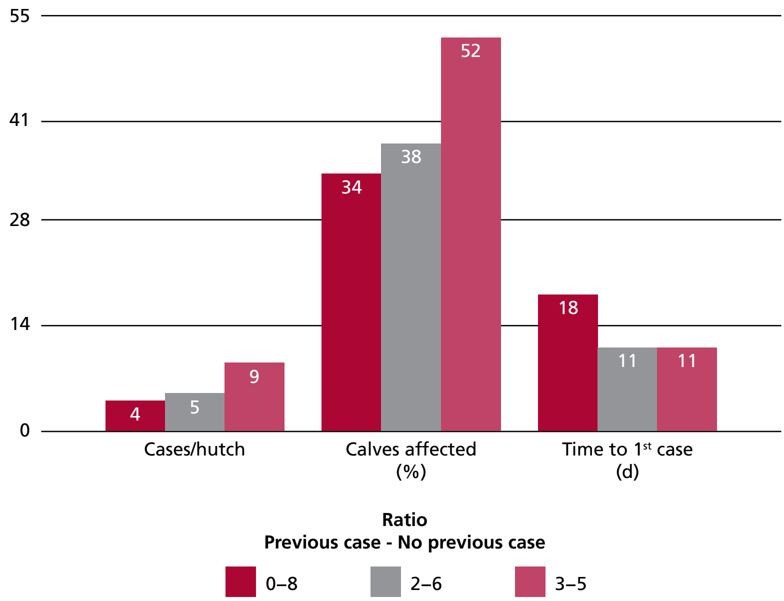


FIGURE 3
Forming groups of eight animals based on respiratory history allows improvements in welfare and health as well as performance



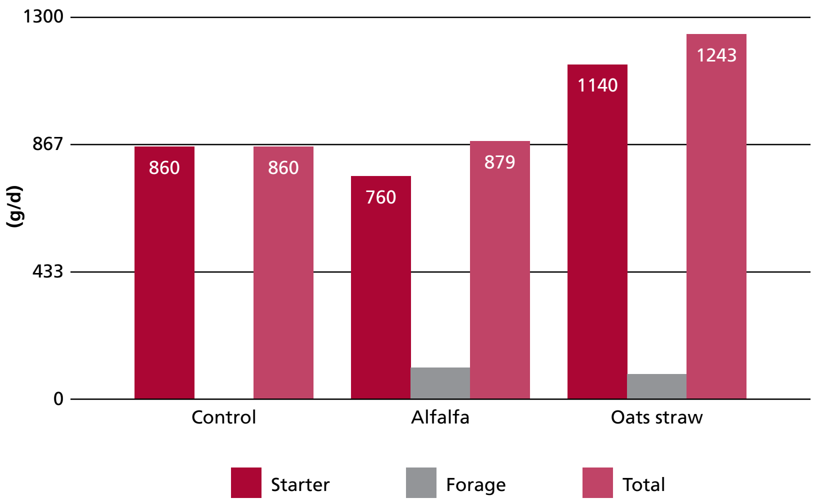
Note: One group had eight calves with no previous history of disease; a second group had six calves with no previous disease and two with a previous case; and a third group had five animals with no previous case and three with previous history of disease.

Finally, total nutrient intake decreases immediately after weaning and this may potentially expose animals to stress and reduced resistance to infection. The reduction in nutrient intake at weaning can be minimized by weaning based on solid feed consumption or progressively decreasing milk allowance. An effective alternative (due to its relatively low cost) consists of fostering solid feed intake, in addition to the starter feed, by offering chopped (less than 2.5 cm) straw or poor quality hay to calves in a separate bucket. Castells *et al.* (2012) reported that offering this type of chopped forage increases total solid feed intake compared with calves that are only offered a pelleted starter feed (Figure 4). Improved solid feed intake means more rumination, less non-nutritive oral behaviours, improved health and welfare.

RETURN ON THE INVESTMENT NEEDED TO ATTAIN RAPID GROWTH RATES EARLY IN LIFE

Bach (2011) used a data set containing records from 7 768 Holstein heifers born between 2004 and 2006 that were raised in a contract heifer operation in Spain and returned to their herds of origin (133 herds in total) before calving. Heifers that reached second lactation had a higher daily growth rate (0.8 ± 0.04 kg/day) between 12 and 65 days of age than those that did not (0.7 ± 0.04 kg/day). Thus, not only is the attainment of rapid

FIGURE 4
Total solids intake as affected by additional supplementation of chopped alfalfa hay or chopped straw (about 2 cm)



growth rates early in life more economical because feed efficiency is higher at this time, but the return on the investment is also greater, with improved longevity and welfare benefits.

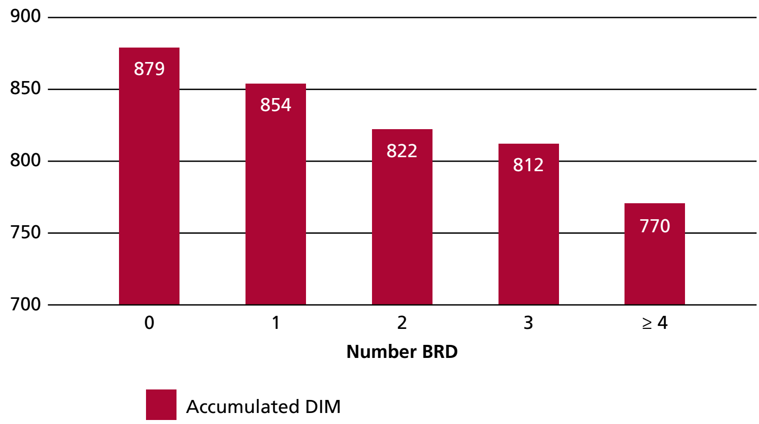
In addition, increased growth early in life has been shown to be associated with improved milk production in the first lactation, as noted by Bach and Ahedo (2008). A study conducted at Spain's Institute for Food Research and Technology (IRTA), using data from a contract heifer operation, showed that for every 100 g/day additional growth during the first 56 days of life, calves produced an additional 180 kg of milk during the first lactation. Thus, calves following an intensive liquid feeding programme with a growth rate of one kg/day are likely to produce an additional 900 kg of milk during their first lactation compared with calves reared on a traditional system gaining about 500 g/day.

Finally, as described above, grouping based on disease history reduces the overall incidence of respiratory problems and improves animal welfare. In addition to the economic savings associated with decreased disease, an improvement in cow longevity can also be expected. Bach (2011) has shown that as the number of respiratory cases a calf incurs increases, the number of productive days decreases (Figure 5).

CONCLUSION

Improving the care of young calves by supplying increased amounts of milk or milk replacer and fostering solid feed intake by providing chopped straw or poor quality chopped grass hay, and grouping animals based on their health records, will not only improve growth rate and reduce morbidity (both of which would result in improve welfare), but will also lead to a less expensive heifer at calving, and an adult animal with improved longevity and increased milking performance.

FIGURE 5
Relationship between number of respiratory cases suffered before first calving and number of productive days (accumulated days in milk) of dairy cows



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Management issues with dry cows and a new feeding system for improved health, welfare and performance

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MAIN MESSAGES

- The incidence rates of periparturient issues in dairy cows remain high on many farms, with associated effects on post-calving appetites, increased body condition loss and compromised fertility; all have major welfare as well as financial implications for the dairy farmer.
- There is surprisingly little research evidence supporting the efficacy of the current far-off/close-up feeding approach for dry cows, and experience indicates that such systems are not delivering the desired outcomes.
- A novel system of controlled-energy high-fibre (CEHF) provision is advanced, recognizing the importance of mixed ration feeding to ensure consistent consumption of the complete ration.
- Evidence from over 270 farms adopting the CEHF system indicated an almost threefold reduction in the incidence of periparturient health issues following full adoption of the CEHF system; the financial benefits from this system in terms of reduced veterinary costs, increased cow performance and reduced herd culling are considerable.

ACRONYMS

AYC	average yielding cow
BC	body condition
BHB	beta-hydroxybutyrate
CEHF	controlled-energy high-fibre
DM	dry matter
HYC	high yielding cow
IGF-1	insulin-like growth factor 1
LH	luteinizing hormone
NEFA	non-esterified fatty acids
VLDL	very low density lipoprotein
ME/kg	metabolizable energy/kilogram

INTRODUCTION

From the cow's perspective, the dry period presents an opportunity for metabolic recovery following the demands of the previous lactation. While foetal growth rate increases exponentially at this time, total nutrient requirements of the cow remain relatively low, a summation of cow maintenance, advancing foetal growth and tissue regeneration, including the udder.

Many farmers view the dry period as an opportunity to reduce management inputs, with less attention given to the cow's nutritional and welfare needs. This is certainly the case on many farms during the first part of the dry period, known as the 'far-off' period, where interventions can be minimal. This is followed by the 'close-up' period when, leading up to calving, most farmers increase ration nutrient density and feeding rate. This practice, based on recommendations by nutritionists or historical practice, aims to "steam-up" the cow in anticipation of her increased nutrient demands after calving. Despite extensive adoption of this approach, there is surprisingly little research evidence supporting its efficacy (Drackley & Dann, 2008). Many farms continue to experience high incidence rates of periparturient issues, compromised feed intakes after calving and increased body condition loss, with associated effects on fertility, all of which have welfare implications.

This paper reviews these issues and presents an alternative dry cow feeding system which is gaining considerable success as demonstrated by field data and recent research (Richards *et al.,* 2009). In this respect, Cunningham (2004) concluded that today's dairy cows, often with significantly improved genetic potential to produce milk, are inherently no less fertile or more prone to production-related diseases than the cows they have replaced. Rather, it is the way cows are managed, especially their nutritional management, that is contributing to many of the health and welfare problems occurring on dairy farms.

FERTILITY

Overall fertility of dairy cows is declining across the world (Butler & Smith, 1989; Smith & Wallace, 1998), evident in both high (Beever *et al.*, 1999) and low yielding herds, including pasture-based cows (Mee, 2004). Records indicate a progressive one percent unit annual decline in first service conception rate, requiring more breeding events to establish a successful pregnancy (Royal *et al.*, 2000). This inevitably increases calving intervals, a major issue in spring-calving herds, where tight calving patterns are targeted to meet the spring grass flush. It also increases the dry period, of concern to householder herds with low cow numbers where there is high reliance on income from daily milk sales. Infertility remains the major reason for premature culling of cows, impacting adversely on lifetime milk production. Recent estimates suggest UK dairy cows complete an average of 3.3 lactations before culling, contrasting with 4.8 lactations in 1975. The position is worse in the United States. Collectively, poor fertility through lost production, lost opportunities and lost cows add significantly to the overall costs of milk production (Beever, 2004).

Genetics, management and nutrition can all be contributory factors to declining fertility. Over recent years, significant herd consolidation has occurred in many countries, with fewer herds and larger herd sizes. With more cows being managed per available staff member, and a declining availability of qualified dairy staff, many cows now receive less individual attention, which may have contributed to the decline in fertility. Further to this, most dairy businesses have experienced only modest financial returns over the last 15 years or so; Colman *et al*. (2004) reported that 60 percent of all milk sold by UK farmers in 2002 incurred a net financial loss. As a consequence, infrastructure investments have declined, leading too many farms with inadequate cubicles, poor feed and water facilities, inadequate lighting and poor walking surfaces, all impacting negatively on cow welfare and performance.

Against this, there have been significant advances in ruminant nutrition science, with many of these findings now embodied in sophisticated rationing systems for dairy cows. But the standard of dairy cow nutrition provided for and adopted by many herds has not progressed at the same rate, with many farms still failing to meet the more exacting demands of the modern dairy cow. Over-dominance by the feed trade, with over-reliance on purchased concentrates and reduced recognition of home grown forages and feeds, has contributed to this effect.

It is argued that the declining fertility which many herds are experiencing has an important underlying nutritional element. With closer attention to the nutritional needs of the dry cow, significant improvements in herd fertility could be achieved, without recourse to major interventions including expensive veterinary products or a possible breed change. Improved management of the cow during the dry period has the potential to improve overall cow wellbeing and longevity.

BODY CONDITION (BC)

Significant loss of body energy may occur in early lactation if feed intake or the efficiency with which that feed is digested by the cow fails to meet the demands of milk production (Bauman & Currie, 1980, Veerkamp & Emmans, 1995). Villa-Godoy *et al*. (1988) concluded that energy intake was the main factor contributing to body energy loss in early lactation, while Veerkamp & Brotherstone, (1997) argued that increased milk yield was a more pronounced determinant of BC loss. Over-feeding of protein in early lactation, often to stimulate milk production, can increase BC loss. Meanwhile, a suboptimal supply of protein can affect both feed intake and digestive efficiency, both of which can promote body condition loss as the cows' potential to produce milk prevails.

The rumen is the key driver of feed intake and efficient feed utilization, both of which can significantly affect overall cow performance. Data with pasture-fed cows led Buckley *et al*. (2003) to conclude that "reproductive performance, especially the probability of conception, may be negatively associated with the magnitude and duration of negative energy balance in early lactation". Previously, Butler & Smith (1989) showed cows losing between 0.5 and 1.0 BC score units between calving and first service had a mean pregnancy rate to that service of 53 percent compared with only 17 percent for cows losing over 1.0 BC score at this time. Subsequently, Beam & Butler (1999) reported that increased negative energy balance reduced the pulse frequency of luteinizing hormone (LH), with a direct impact on the subsequent fate of the developing follicle.

Meanwhile, Mee (2004) noted that between 1991 and 1998, first service conception rate in pasture fed cows declined from 60 percent to 54 percent while the calving interval increased by 10 days and the number of cows experiencing abnormal cycles increased from 13 percent to 26 percent. Mee (2004) also noted less overt oestrus behaviour in many cows, concluding that "strategies are required to improve or halt the decline in reproductive performance (and that) these must include feeding systems to reduce negative energy balance and maintain body condition".

Hattan *et al*. (2001) examined the performance of average yielding (AYC; 8 000 litre) and high yielding (HYC; 11 000 litre) cows. From a pre-calving BC score of 2.9, AYC lost an average 0.8 BC score over the first five weeks of lactation, followed by a period of reasonable stability and then modest gains as lactation advanced. In contrast, HYC, with a similar pre-calving BC score, showed a deeper and more extended BC loss through to week 11 and an average BC score of 1.6. Thereafter, the BC score remained relatively stable until the study terminated at lactation week 24, by which time the BC score differed by 0.7 between the two groups.

Parallel studies of energy metabolism (Beever, 2003) estimated 60 kg loss in body fat by lactation week 11 in HYC, with a net gain of 28 kg body fat between weeks 21 and 30. Thus by 210 days in milk, these cows had only replenished 55 percent of the body fat lost during early lactation.

With lower yielding cows fed more modest rations and lower peak milk yields, Sutter & Beever (2000) determined a negative energy balance in lactation week 1 equivalent to 3.2 kg body tissue/day, declining to 1.7 kg/day between weeks 2 and 4, and further to 1.1 kg/day, but the cows were still in negative energy balance when the study terminated at lactation week 8. Mobilized tissue over the first eight weeks of lactation was sufficient to support the production of 300 litres of milk, from a total recorded production over that period of 1 820 litres.

It is concluded that in many cows the extent of body condition loss in early lactation can be quite severe. As Veerkamp & Brotherstone (1997) indicated, this may be driven by the increased potential of many cows to produce high volumes of milk, but equally the importance of optimizing energy intake in early lactation as considered by Bauman & Currie (1980) and Veerkamp & Emmans (1995), cannot be overlooked. In this respect, the relative amounts of adipose tissue in the periparturient cow may be important and where cows have increased fat deposits this may lead to depressed appetites after calving. Loss of BC per se is not necessarily a welfare issue, unless the cow becomes seriously debilitated, but the knock-on consequences for the cow and the farmer can be quite severe.

FAT METABOLISM IN LACTATING DAIRY COWS

Where the extent of fat mobilization approaches 60 kg during early lactation, it is not surprising that Reynolds *et al*. (2003) reported major changes in the hepatic flux of non-esterified fatty acids (NEFA) as cows progressed from late pregnancy into lactation. Prior to calving, NEFA flux to the liver was relatively stable, equivalent to 1 mole palmitate/day. However, after 11 days post-calving, this had increased to over 5.5 moles palmitate/day, declining gradually thereafter as lactation progressed, even though it still remained at twice the pre-calving baseline by lactation week 10.

The liver is the major site of fat metabolism and under normal conditions significant amounts of NEFA will be oxidized to support the cow's energy requirements. Alternatively, and especially when hepatic NEFA load is increased, NEFA may be exported from the liver as very low density lipoproteins (VLDL), to be metabolized in other tissues. In this way, significant amounts of mobilized body fat support the synthesis of milk fat, especially during early lactation when feed intake fails to match milk output. But when normal oxidative or transport capacities of the liver are exceeded, NEFA are either partially oxidized, with an associated rise in plasma ketones, or accumulate within liver cells. Drackley (1999) suggested that the rate of fat deposition in the liver may approach 500 g/day during early lactation and, if maintained, would be sufficient to fully saturate liver cells with fat within two weeks. This will inevitably affect other hepatic functions. Strang *et al*. (1998) reported a negative linear relationship between cellular fat concentrations and rate of conversion of ammonia into urea. They added that up to 60 percent of dairy cows may have liver fat levels in excess of 10 percent on day 1 postpartum, sufficient to cause a 20 percent reduction in the rate of urea and glucose production by the liver.

Meanwhile, a survey from Michigan State University of over 1 500 cows found positive relationships between periparturient NEFA levels and the incidence of dystocia, retained foetal membranes, mastitis, ketosis and displaced abomasums, all of which are potential welfare issues. Added to which, Wathes *et al*. (2003) noted that both BC at calving and extent of BC loss post-calving affected the interval to a successful conception, with a higher loss of BC associated with reduced circulating IGF-1 levels. Further, cows with extended inter-luteal intervals or prolonged anoestrus (usually after an oestrus event) had higher levels of NEFA and ß-hydroxy butyrate (BHB), both indicative of increased BC loss. Kruips *et al*. (2001) found significant relationships between plasma NEFA and liver triacylglycerol levels and the interval to first ovulation in cows that were deliberately over-conditioned prior to calving.

It is concluded that cows showing excessive BC at calving, as well as high rates of BC loss after calving, are likely to be more difficult to rebreed, and have more metabolic issues during the periparturient period. In turn these events can impact negatively on animal welfare and longevity.

CONTROLLED-ENERGY HIGH-FIBRE FEEDING STRATEGY

Contrary to popular belief, dry cows do not limit feed intake to their nutrient, especially energy, requirements. With sufficient opportunity, they may consume as much as 70 percent excess, resulting in increased body fat deposition. After calving, this additional energy will be used to support milk production, with an associated reduction in feed intake. Further, recent scientific evidence suggests that nutritional management of the dry cow during the far-off period may be as important as it is considered to be during the close-up period.

Tackling both issues, a novel strategy of controlled energy feeding during the whole dry period has been developed, and shown to bring significant improvements in cow health during the periparturient period and subsequent lactational performance, with obvious gains in animal welfare.

In a cohort of over 600 000 cows removed due to death or culling from 6 000 herds over five years, Fetrow *et al*. (2006) found that 25 percent left within the first 60 days after calving. This represents a serious waste of animal and financial resources, given the accrued costs of breeding, gestation feeding and calving against a significant loss of the cow's potential to produce milk during that lactation. Such premature losses also impact on lifetime milk production, while clearly having important welfare implications. It is argued that a significant part of this loss could be averted by improved nutritional management of the dry cow.

Dann *et al*. (2006), Douglas *et al*. (2006) and Janovick & Drackley (2010) have shown that excess energy intake, even in dry cows of low to average BC, can predispose health and welfare issues around calving and the early post-calving period, including dystocia, fatty liver and ketosis. Part of the rationale behind increased energy feeding prior to calving was the notion that the cow's appetite generally declines as calving approaches. But Grummer *et al*. (2004) Richards *et al*. (2009) and Janovick & Drackley (2010) have argued that the decline in dry matter intake is more closely related to ration energy density.

Beever (2006) and Drackley & Dann (2008) proposed a feeding system to control energy intake during the dry period, while at the same time ensuring that all other nutrient requirements are met. A ration with high levels of bulky forage, including significant amounts of cereal straw and restricted amounts of the intended lactation forages and concentrates is recommended. Pasture availability of grazing cows should be limited and an alternative forage containing less potassium (e.g. maize or cereal silage) provided. With high levels of cereal straw, total ration energy density is reduced (circa 9 MJ of ME/kg of DM), but achieved DM intakes of the total ration approaching 12 kg/day are sufficient to meet the energy requirements of some of the largest dairy cows. A typical ration formulation for housed cows would be 50 percent cereal straw, 30 percent lactation forages and 20 percent lactation concentrates (DM basis), with a suitable dry cow mineral. This ration is fed throughout the whole dry period, abandoning the historical far-off/close-up approach.

Central to this strategy, however, is feed presentation. Providing cereal straw as a separate feed is no guarantee that cows will consume the requisite amount of this feed to reduce overall consumed energy density. Cows naturally select more palatable feeds if given the opportunity, thus defeating the overall objective to lower ration energy density. Consequently all forages and concentrates should be provided as a mixed ration, with forage length suitably processed to ensure minimal feed selection while retaining essential physical structure to optimize rumen function. This can be achieved with suitable ration mixing equipment but as Humphries *et al*. (2010) showed, some feed mixing systems are considerably more suitable for producing well-mixed rations that minimize feed selection and optimize physical fibre content.

Colman *et al*., (2011) presented evidence of the impact of adopting a controlled-energy high-fibre (CEHF) mixed ration feeding system for dry cows. Prior to adoption of the CEHF system, a cohort of 277 dairy farms in France, Ireland, Sweden and the United Kingdom, with over 27 000 cows, averaged 45.5 health issues per 100 cows around the calving period, including assisted calvings, retained foetal membranes, milk fever, displaced abomasums and ketosis. All of these can be considered as potential welfare issues, of which milk fever can be particularly debilitating while in some cases, displaced abomasums can be life-threatening. Six months after adoption of CEHF, overall incidence rate had declined to 16.2 cases per 100 cows, with over 75 percent reductions in milk fever, ketosis and displaced abomasums, and more recent field data have confirmed the potential of this approach to reduce periparturient health and welfare issues in dairy cows.

Supporting scientific evidence for CEHF feeding throughout the whole dry period has been provided by Richards *et al.* (2009). Three treatments, all fed *ad libitum*, comprised

(i) **CEHF**, from drying-off until calving, with 40 percent (DM basis) wheat straw inclusion; (ii) **control**, a moderate-energy diet fed from drying-off until calving; and (iii) a **2-stage** system with CEHF fed from drying-off until 21 days prepartum, followed by control until calving.

Noticeably, control cows consumed high levels of feed until week 4 before calving, after which a sustained reduction was noted. On the other hand, CEHF cows had lower but more stable intakes through to calving. Initially 2-stage cows behaved as CEHF cows but, following the ration change, there was an immediate feed intake increase before declining in line with control cows through to calving. Feed intakes post-calving were improved on CEHF with a slower increase noted for control cows.

As expected, control cows gained BC prior to calving followed by an accelerated loss, while CEHF and 2-stage cows showed minimal change during the dry period, with substantially reduced losses thereafter and all treatments were largely indistinguishable by lactation week 10 with respect to BC. CEHF cows showed a slightly slower rise in milk production, although this was not apparent in first calvers.

However there were notable changes in plasma NEFA and BHB levels. While NEFAs increased during the calving period on all treatments, CEHF cows showed a much reduced peak compared with control cows, while 2-stage cows showed some attenuation of this increase. Further, levels were still elevated at lactation day 40 in control cows with CEHF and 2-stage cows showing much earlier returns to base levels (15 and 20 days respectively). Changes in BHB were even more pronounced: base levels restored by day 10 in CEHF cows compared with day 16 in 2-stage cows, while levels were still elevated at day 60 in control cows. Supporting evidence showed that control cows had significantly higher levels of fat accumulation in the liver than 2-stage and especially CEHF cows, while changes in plasma insulin levels strongly suggested that control cows were experiencing insulin resistance, which in other studies has been shown to affect fertility adversely.

Assessment of the impact of any management changes on dairy cow fertility requires dedicated longitudinal studies involving extensive measurements on a large number of cows. Neither Colman *et al*. (2011) nor Richards *et al*. (2009) provided such data and thus conclusive evidence of the possible benefits of the CEHF strategy on fertility is not available. However many of the responses noted above, especially improved metabolic health and reduced body condition loss, can be advanced as factors likely to contribute to fewer cows experiencing reproductive issues. There is considerable anecdotal evidence to support this claim, with clear indications of their effect on cow welfare and longevity.

In summary, and beyond any perceived improvement in fertility, data obtained from the above research and on-farm studies provides convincing evidence that controlling energy intake during the whole dry period to meet but not exceed the animal's requirements results in significant improvements in cow health and welfare around the calving period, and prepares the cow for a more successful lactation and hopefully a less arduous breeding event. The welfare benefits of this approach should be self-evident to the reader and are most obvious when seen on-farm.

In addition, the CEHF system brings important monetary gains through reduced interventions (and associated veterinary costs) and improved lactational performance. For those herds involved in the study, and using industry-accepted guideline costs, it was estimated, that before intervention compromised health around the calving period amounted to over

€9 500/year for a 100 cow herd (€95/cow), reduced to €3 200/year after adoption of CEHF. This difference could be worth an additional 1.1 cents for every litre of milk produced for an average yielding herd.

CONCLUSION

There is clear evidence that metabolic and health issues around the calving event impact negatively on cow welfare and farm profitability. The current system of far-off/close-up feeding has failed to deliver the expected gains, with many farmers seeking expensive interventions, and general cow welfare showing no substantial improvement. The CEHF system, backed by research and farm evidence, is simple to execute and has been shown to overcome many of the health and welfare issues experienced by many cows around the calving period. However, the importance of ration presentation to avoid ration selection and promote optimal rumen function cannot be overemphasized if the desired gains are to be achieved.

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The relationship between nutritional status and bovine welfare associated to adoption of intensive silvopastoral systems in tropical conditions

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MAIN MESSAGES

- Intensive silvopastoral systems (ISSs) ensure the availability of a high quality diet to cattle, ensuring their welfare and complying with the principles of freedom from prolonged hunger and thirst.
- The ISSs reduce the negative effects of seasonal (rainy and dry seasons) variation in forage availability typically observed in the Neotropics, a zone increasingly affected by the negative effects of global climate change.
- The ISSs can create a microclimate suitable for the adaptation of animals to heat, which improves their comfort and consequently their health status.

ACRONYMS

ADF	acid detergent fibre
AU/ha	animal unit/hectare
BC	body condition
CP	crude protein
DM	dry matter
EE	ether extract
GE	gross energy
IRR	internal rate of return
ISS	intensive silvopastoral system
LWG	live weight gain

NDF	neutral detergent fibre
NFE	nitrogen-free extract
NPV	net present value
QBA	qualitative behaviour assessment
T-df	tropical dry forest

INTRODUCTION

All metabolic pathways that enable life processes require specific nutrients supplied in correct amounts. Consequently, access to adequate amounts of a well-balanced diet is a primary need for all animals and has been identified as one of the major animal welfare concerns in modern livestock production systems.

In Colombia, as well as in other neo-tropical countries, animal agriculture is mostly practised in large, open pasture grasslands, with few or no accompanying trees. Both during the rainy and dry seasons, animals commonly face nutritional problems due to low pasture productivity, which leads to animal welfare problems associated with cases of prolonged hunger and thirst, which in turn are compounded by and are related to heat stress problems, plague infestations and disease outbreaks.

Changing from the use of single pasture grasslands to intensive silvopastoral systems (ISSs) is a successful example of how the adoption of new technologies can help alleviate nutritionally-related welfare problems in cattle. The ISSs respond to the need of converting tropical animal agriculture into a profitable and environmentally-friendly system, offering more job opportunities, high quality products (meat, milk and leather) and high animal welfare standards, besides the opportunity of harvesting wood, fibre and fruit from the trees.

There are successful case reports on the use of ISSs from Colombia and currently these systems are being implemented in Argentina, Brazil and Nicaragua. Similar systems are also widespread in Australia, although with lower density of trees. The technological development of ISSs has been supported by scientific studies in many countries, offering a strong basis for practical implementation of these systems.

An ISS can be characterized as a form of agroforestry with high densities of fodder shrubs (from 5 000 to more than 30 000 shrubs/ha, such as *Leucaena leucocephala* cv. Cunningham and *Tithonia diversifolia*) associated with improved high-biomass producing grasses and timber trees, fruit trees or palms (from 50 to 500 trees/ha). The ISSs use models of intensive rotational grazing, dividing the paddocks with electric fences, and offering constant water supply for all animals and mineralized salt *ad libitum*. By doing so, it is expected to sustain high animal densities and to achieve high milk and meat production per unit of area.

The term “intensive” refers to the high efficiency of biological processes such as photosynthesis, biological nitrogen fixation, phosphorus solubilization, biological control of plagues, water regulation and improved biological activity of the soil. Intensity should not be confused with high use of capital, human work, mechanization, oil-based inputs (agrochemicals) or concentrates.

In Colombia, 70 percent of cattle farms are extensive and characterized by low biological and economic efficiencies as a result of poor nutritional quality and lack of availability of pasture, especially during the dry season. This situation becomes more critical as grazing areas commonly show an advanced state of degradation with losses in biodiversity and of soil organic matter. This leads to cattle herds presenting low productive and reproductive rates and reductions in the profitability of the cattle business.

ISSs have proved to be a technological alternative that improve the competitiveness of livestock enterprises, and significantly improve the indicators of plant and animal production as management practices introduced as part of these systems make for more efficient livestock production.

NUTRITIONAL VALUE OF ISSs

The forage diet typically offered in the ISSs often contains high protein concentrations and digestibility (Table 1), a nutritional value similar to that of *Medicago sativa*, a highly valued forage. For ISS planted with leucaena, its low NDF may be associated with higher packing of the diet in the rumen and with an increase in dry matter intake, rate of passage and animal productivity.

Increases in animal production commonly reported with the adoption of ISSs are explained partly by leucaena's condensed tannin content, which prevents excessive protein degradation in the rumen, allows proteins to be digested in the intestine and improves the quality of protein the animal receives. Reports indicate that tannins can reduce methane emissions in ruminants, promoting better use of consumed forage and improving the energy metabolism. Table 1 shows some nutritional characteristics of forages commonly used in ISSs arrangements.

CASE STUDY 1

EL HATICO, NATURAL RESERVE OF THE CIVIL SOCIETY, SPECIALIZED MILK PRODUCTION WITH ISSs UNDER TROPICAL DRY FOREST CONDITIONS

El Hatico adopted silvopastoral systems in 1970 and has pioneered their use. This farm is located in the fertile flatlands of the Cauca River Valley in Colombia, at an altitude of 1 000 m, with an average temperature of 24 °C and an average of 800 mm of bimodal rainfall. Until 1970, the farm had conventional ranching practices: pastures with a few scattered

TABLE 1
Typical nutritional characteristics of forages in typical ISSs diets

Forage	*C. plectostachyus*	*P. maximum* cv. Tanzania	*L. leucocephala*
DM (%)	22.36	19.92	21.99
CP (%)	8.59	10.07	27.68
NDF (%)	69.14	66.78	32.42
ADF (%)	35.43	35.35	12.30
Lignin (%)	5.40	6.30	7.70
EE (%)	1.23	1.24	2.31
Ash (%)	9.29	9.97	6.92
NFE (%)	11.85	12.02	32.19
GE (Mcal/kg DM)	3 629	3 801	4 170

trees (ten trees/ha), use of herbicides for weed control, irrigation in dry periods, chemical fertilization and a stocking rate below three cows/ha. In 1993, leucaena was planted at high density for browsing. Three years later, this family enterprise was awarded environmental certification.

The ISSs and rotational grazing systems used over the past 18 years have facilitated an increase in stocking rates to 4.3 dairy cows/ha and milk production by 130 percent, without use of chemical fertilizers. El Hatico averages 3 030 L of milk per lactating period, for an annual production of 15 805 L/ha. The percentage of fat in milk is 3.8 and that of protein is 3.25. The animal mortality rate is five percent for the young and 0.5 percent for adults, and the birth rate is estimated at 95 percent, with a calving interval of 12.8 months and age at first calving of 30 months.

In the region, production of edible biomass for animals, which is highly dependent on the use of nitrogen fertilizer, is about 20 tonnes of DM/ha/year, while the ISSs produces about 30 percent more biomass of higher nutritional quality (Table 2). Using grass, legume shrubs and trees in high density, it is possible to produce at least five times more milk and higher quality milk than in an open system without trees. In El Hatico, the area used for grazing in ISSs is 55 ha with a production of milk per hectare per year close to 16 000 litres; as a result, efficiency in land use is higher than in conventional farms. These results depend on proper management of grasslands.

The relationship between improved nutrition and enhanced animal welfare became evident in work recently carried out by the Center for Research on Sustainable Farming Systems (CIPAV) in different ISSs models including the model used in El Hatico. Because the results in animal welfare indicators are similar for all models tested so far in ISSs, they are presented in detail below. Briefly, animals in the ISSs spent more time foraging, had more cycles of consumption and rumination, and spent less energy in searching for forage, all of which are reflected in the maintenance of optimal body condition throughout the year. Other indicators of animal welfare as such as lying down, health and emotional status measured by qualitative behaviour assessment (Wemelsfelder, 2007), have shown higher rates of welfare when compared with conventional production models without trees.

CASE STUDY 2

EL CHACO FARM, BEEF PRODUCTION WITH ISSs UNDER TROPICAL DRY FOREST CONDITIONS

This farm is located on the terrace of Ibague, Tolima, at an altitude of 605 m and an average rainfall of 1 200–1 300 mm. The climate of the region corresponds to the life zone of tropical dry forest.

Animals used for fattening on this farm are *Bos taurus x Bos indicus* crosses. The breeding herd is mostly the product of Holstein x Gyr crosses with pure Guzerá and Brahman bulls, which transmit characteristics of resistance to heat stress and increased milk production.

Work at El Chaco has shown how in the upper Magdalena, by using leucaena and star grass, it is possible in 12 years to convert a farm with compacted soil, a stocking rate of 0.5 hd/ha, a calving interval of 15 to 18 months and an output of 120 kg of beef/ha/year as weaned calves, to a farm that today has a stocking rate of 3.5 cows/ha, producing on average 10L of milk/cow (13 000 L/ha/year), with a calving interval of 14 months and

TABLE 2
Production parameters for grass monoculture pastures and ISSs with scattered trees in El Hatico

Parameter	Conventional livestock systems with high use of urea	ISSs with scattered trees
Forage production (Mg DM/ha/yr)	23	30
Stocking rate (AU/ha)	3.5	4.3
LWG (g/heifer)	450	750
Milk production (L/ha/yr)	9 000	15 805

weaning weights of calves at 10 months of age between 150 and 160 kg (more than 400 kg of beef/ha/year as weaned calves).

The productive results observed at El Chaco are explained by the characteristics of the system. The forage availability is 25 percent higher than in systems without trees. Leucaena consumption reaches 30 percent of the diet. In addition, our studies have shown that the consumption of forage in the ISSs is greater and the time spent on consumption is 17 percent higher than in monoculture pasture systems, even at midday which corresponds to the hours of greatest brightness and highest daily temperatures.

The association between nutrition and animal welfare on the El Chaco farm is described briefly here. Animals in a pasture without trees do not consume forages during the midday hours when radiation and temperature reach their highest values, unlike the behaviour of consumption in ISSs in which animals show forage consumption cycles even at these times. The temperature differences in pastures without trees is up to 7 °C higher and may explain increased forage consumption in the ISSs where animals maintain thermal homeostasis and are more comfortable.

BIODIVERSITY

When farmers using ISSs were surveyed, a high percentage of them reported increased biodiversity in their farms, with increased number and diversity of birds (71 percent), increased plant and animal diversity (54 percent), more frequent sightings of wild mammals (36 percent) and more sightings of threatened or rare species (11 percent). Increased biodiversity allows the application of conservation incentives such as payment for environmental services. These experiences suggest that the ISSs can be integrated with other strategies at landscape level as part of connectivity corridors for biodiversity conservation and enhancement of environmental services in agricultural landscapes. Today, many of the remaining unprotected forests of high conservation value are housed within a matrix formed by cattle pastures in monoculture with a small number of trees.

BEEF QUALITY

Recent research shows that the quality of meat produced in systems with leucaena may be equal to that obtained in feedlot systems where animals are fed with grain. The comparison was based on weight and age of the animals and their meat characteristics: thickness,

TABLE 3
Production parameters for monoculture grasslands and ISSs with 500 timber trees/ha in El Chaco

Parameter	Conventional systems	ISSs with scattered trees
Forage production (Mg DM/ha/yr)	4	28
Stocking rate (AU/ha)	0.6	3.5
LWG (g/steer)	453.8	856
LWG (g/heifer)		492
Beef production (kg/ha/yr)	99.3	1 090
Milk production (L/ha/yr)		14 000

colour, leanness, marbling and presence of unsaturated fatty acids and conjugated linoleic acid (Corral, 2011). These features meet the certified organic meat production requirements of the European Union and Japan. When compared with intensive feeding systems in confinement, the ISSs have better animal welfare indicators and less environmental impact (reducing water and carbon footprints).

ECONOMIC PROFIT OF THE ISSS

The consolidated ISSs are financially viable because they are at least as productive as the most improved pastures using irrigation and fertilization, but have lower maintenance costs. In some regions of Colombia and Mexico, ISSs even compete with intensive agricultural systems on fertile land. The biggest economic benefit of ISSs is transforming an extensive cattle industry with increasing resource degradation and low productivity (negative margins) into a system with net present values (NPV) and internal rates of return (IRR) attractive to small and medium producers, who can cover interest costs of rural credit loans. When timber trees are grown in ISSs at 40 percent of tree densities used in conventional timber tree plantations, financial returns are improved due to the income obtained when timber trees are harvested (12 to 20 years, depending on the species), despite systems having a slightly lower stocking rate.

Table 4 shows large differences in the NPV and IRR between extensive degraded pastures and ISS with scattered trees and with 500 timber/ha. Inputs for ISSs are greater, but the increased profitability from the system will pay for the investments in less than five years. In addition, the initial input creates a sustainable and more diverse system with improved animal welfare and productivity.

Accordingly, grazing systems developed by the association of several plant species (grasses, timber and shrubs in high density) such as ISSs, are successful models for converting traditional livestock production systems without trees into sustainable production systems, achieving greater profitability and products per unit area. This has been considered in the design and implementation of a stimulus package both in Colombia and Mexico.

TABLE 4
Differences in net present value (NPV) and internal rate of return (IRR) between extensive degraded pastures and ISSs with scattered trees and/or with 500 timber trees/ha

Economic Indicators	Extensive grazing	ISS plus scattered trees	ISS with 500 timber/ha
Investment/ha (US$)	277	1 882	2 532
Stocking rate; AU/ha	0.6	3.0	2.55
NPV (US$)	369	3 497	23 096
IRR – Beef production	Non-viable	13%	29%
IRR – Milk production	11%	12%	27%

Note: Annual discount rate of 12%

NUTRITION EFFECTS ON ANIMAL WELFARE IN TROPICAL LIVESTOCK

Forage intake is as important as its nutrient composition. In the case of ruminants, environmental, plant and animal related factors affect forage intake. With the implementation of ISSs, farmers can offer appropriate nutrient composition of forages throughout the year and benefit from the high resilience of this system. Thus plants provide enough nutrients to meet animals' needs, regardless of weather conditions. On the other hand, animals do not have the same access to nutrients throughout the year in tropical single-grass systems. In the best seasons, they will have access to forage biomass, but in times of climate extremes, they will only have access to plants that are highly lignified or very immature, and therefore compromise their welfare.

NUTRITION AND BODY CONDITION

Body condition (BC) is a good indicator of animal welfare because it reflects the body fat content, representing the nutritional status of the animal as a result of body reserves. BC has health implications and its excesses and deficiencies are related to alterations in the animal reproductive and immune systems, among others. Low BC reflects prolonged hunger or disease of the animal because its energy needs are not met.

In four studies conducted by our research group in different ISSs in different seasons throughout the year, we found that animals BC scores ranged within 3 and 4 based on a 1–5 scale, indicating that animals maintain an adequate BC, and suggesting an improvement in animal welfare relative to extensive single-grass systems. On the other hand, animals in extensive single-grass systems often show serious problems of BC loss during both the rainy and dry seasons, which are due to starvation.

When animal welfare was evaluated based on the four principles proposed in the European Union-funded Welfare Quality Project® reports, we found that the first principle "Absence of prolonged hunger" obtained a score superior to 98/100 in all ISSs. This corroborates the benefits in animal welfare obtained by the good nutrition offered in ISSs.

QUANTITY AND QUALITY OF WATER

As any other system, ISSs require the permanent availability of fresh and good quality water for all animals, implying the installation of water supply network systems provided with adequate troughs, preventing the animals from entering directly into bodies of water like rivers, streams, wetlands and springs. The design of water networks should fit the rotation system operated with electric fencing, and troughs should be located to avoid unnecessary walking for the animals, causing waste of energy and trampling of the pasture, and therefore decreasing productivity. This encourages the farmer to protect and improve the quality of this natural resource.

Our results have shown that the maximum distance walked for an animal to obtain water in ISSs is 100 m, but is usually less than 50 m. On the other hand, in pasture systems with no trees, where the availability of good quality water is limited, animals usually have to walk long distances to water, increasing their waste of energy and negatively affecting their welfare.

MINERALIZED SALT SUPPLY

It is known that mineral deficiency produces multiple physiological problems affecting animal growth and health. In ISSs, there is a permanent mineralized salt supply to compensate for the mineral deficiencies of forages and promote food consumption. In monoculture grazing systems, when mineralized salt is supplied but access to water is difficult, animals may suffer from mineral toxicity.

ANIMAL HEALTH

It is known that nutrition plays a key role in the adequate functioning of the immune system and thus maintaining animal health. Grazing livestock in open areas with no trees favours the development of parasites due to conditions of moisture and temperature of the manure. In contrast, our research has shown that trees in the ISSs not only serve as shade and food for the animals but also host functional organisms, favouring a significant natural regulation of the *Haematobia irritans* fly and various parasites. The vegetal layer and the management of ISSs favour the presence of predators such as birds, ants and entomopathogenic microorganisms. All of these factors together are involved in the natural regulation of tick populations.

It has been also hypothesized that cattle have increased resistance to internal and external parasites because the best nutrition and constant supply of feed in the ISSs improve immune response. Furthermore, it has been reported that leucaena and other foliage and fruit trees such as *Guazuma ulmifolia* and *Crescentia cujete* have antiparasitic effects.

BOTANICAL COMPOSITION AND THERMAL COMFORT

The mixed botanical composition of ISSs creates a microclimate that provides comfort for animals. There is a relationship between consumption and thermal comfort because, in the ISSs, animals are favoured by the climate conditions inside the system. One recent study showed that in ISSs animals have 5 °C lower skin temperature compared with animals in open systems without trees. The comfort generated by the ISSs causes animals to eat food even in times of high solar radiation (between 10:00 and 14:00). Plant cover affects the temperature of the lower layer of the system, suggesting that the ISSs have a positive effect on the animals' thermal comfort, not only because of the shadow cast by the trees, but also because of changes in heat transfer in the lower layer.

High temperatures and increased solar radiation due to climate change may be major problems in production systems in neo-tropical zones. To mitigate their adverse effects on animals, we highly recommend the integration of trees and shrubs in livestock systems. The ISSs favour the regulation of environmental temperature by contributing to the dissipation of solar radiation, diminishing the waste of energy by animals and reducing stress.

INTAKE BEHAVIOUR AND ANIMAL WELFARE

In four studies conducted by our research group in different ISSs with conditions similar to the cases reported above, we found that management with electric fencing reduces the rejection behaviour caused by faeces and urine on the forage, compared with continuous systems without trees. In ISSs, faeces are rapidly processed by macro and microorganisms, which in turn allow for their rapid recycling in the system. In monoculture grazing systems, animals spend much time walking in search of edible grass, and their capability to express different behaviours is very limited compared with the ISSs, where they show different social and intake behaviours.

Because emotional status is an important indicator of animal welfare, various methods have been developed to assess it. In the same studies, we carried out a qualitative behaviour assessment (QBA) based on the methodology of Wemelsfelder and described in the Welfare Quality Reports. The QBA is a welfare assessment method that has been developed and validated in recent years in the United Kingdom (Wemelsfelder *et. al.,* 2009). The method relies on the ability of observers to perceive and integrate details of behaviour by estimating animal body language and using emotional descriptors. In this study, four trained researchers used 20 indicators to assess the emotional status of cattle in different silvopastoral arrangements. The results showed almost all animals with good welfare indicators (calm, positively occupied, etc.) while only a few of them showed low welfare indicators (stress, defensiveness, etc.). The highest rating indicator was "positively occupied", which is related to actions like forage consumption, rumination, lying down or social interactions. These positive emotional status indicators are probably related to higher production rates found in the ISSs.

IMPROVING THE HUMAN-ANIMAL RELATIONSHIP

While providing feed to the animals, the rotational system using electrical fencing in ISSs favours constant contact between animals and humans. Our results showed that the reactivity of animals in the cattle chute is lower in the animals in ISS compared with animals in monoculture systems. We used as indicators of reactivity in the chute: the animal's position (standing, kneeling, lying), movement (scale 0–3), respiration (scale 0–3), vocalizations (presence or absence) and kicks (presence or absence), and finally calculating a score on a 0–5 scale.

It was observed that the reactivity of cattle in the chute was significantly lower ($p \leq 0.05$) in the ISSs animals (2.43) compared with the open system (3.33). Moreover, the avoidance distance in most animals in ISS is less than 2 metres, while in the open system with no trees it may be over 20 metres. This is explained by the habituation and good handling in the ISS.

CONCLUSION

The ISS is a successful model of sustainable production in several Latin American countries. There is evidence that ISSs increase animal welfare through the improvement of nutrition, maintenance of optimal body condition, promotion of higher efficiency of the immune system and thus, improved health status, and that the ISSs provide conditions that help animals to cope better with environmental stressors.

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Use of nutraceuticals for improving animal health during the transition period of dairy cows

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MAIN MESSAGES

- The transition period is characterized by frequent inflammatory conditions which are the consequence of disease or tissue damages, and which impair performance and welfare of dairy cows.
- Proper management and nutrition during the dry period and early lactation can contribute to the reduction of several inflammatory phenomena, for example decreased metabolic and infectious diseases, digestive disorders or oxidative stresses.
- Addition of polyunsaturated fatty acids such as omega-3 and conjugated linoleic acid in diet can contribute to modulation of the inflammatory process and attenuation of the systemic inflammatory response.
- Under some farm conditions, this nutritional approach - as well as better dry period care - promotes improvement in animal welfare and performance, leading to improved economic returns.

ACRONYMS

ASA	acetylsalicylic acid
BHB	beta-hydroxybutyrate
CLA	conjugated linoleic acid
NEI/kg	net energy intake/kilogram
PUFA	polyunsaturated fatty acids
ω-3	omega-3 fatty acids

INTRODUCTION

We have recently reviewed the topic of inflammation in transition dairy cows (Trevisi *et al.*, 2011a) suggesting that the periparturient period is of enormous importance in determining health, productivity and profitability. Dairy cows undergo tremendous adaptive changes during the transition from late gestation to early lactation. Metabolic and microbial diseases typical of this period are milk fever, retained placenta, metritis, mastitis, rumen acidosis and lameness, among others. Furthermore, the well-known reduction of immune competence around calving increases the susceptibility to infectious diseases such as metritis and mastitis.

High-yielding cows are particularly susceptible to both infectious diseases and metabolic stress; moreover, they are less tolerant to management mistakes (Garnsworthy and Webb, 1999; Ward and Parker, 1999). This susceptibility is further increased in a period of reduced immunological capacity such as the transition period (Lacetera *et al*., 2007).

TRANSITION PERIOD AND INFLAMMATION

The high occurrence of metabolic and infectious diseases is responsible for the high incidence of inflammatory conditions (Bertoni *et al*., 2008) in the transition period (mostly after calving). The data we obtained have demonstrated that approximately 50 percent of cows in dairy farms tend to produce less milk, lose more body energy reserves, and become less fertile because they suffer from inflammation, which is not always clinically evident. Diagnosis of such a condition is possible via acute phase protein changes: haptoglobin rise and albumin, lipoproteins, and retinol binding protein reduction (less liver synthesis of usual proteins). Interestingly, cows with the worst inflammatory indices appear affected by a larger energy deficiency and increased levels of beta-hydroxy-butyrate (BHB), confirming marked body reserve losses.

INFLAMMATION PREVENTION

Excluding animals with serious health problems, cows with important inflammatory phenomena (clinical or sub-clinical) represent not less than 25 percent of cows in the herd. On average, from our data and those from Illinois University, performance of cows with inflammation was worse than that of cows without inflammation:

- milk yield loss of 6–8 kg/day (at least in first month of lactation);
- longer open days of between 30 and 60 days.

In Italian conditions, this means lower milk income per cow of €2.1/day in the first month (thereafter, the animals tend to recover, but some loss remains). Moreover, each day above 365 days of prolonged calving interval means a loss of at least €10/day for each cow producing 9 000–10 000 kg/lactation (van Eerdenburg, 2008). A total loss of almost 60 + 450 = €510/cow (by taking 45 days as average extension of open days) can at least be foreseen in a high yielding farm; obviously this only affects the 25 percent of cows with mild but important inflammatory problems at calving. The loss calculated here is rough and does not take into account the decrease in milk yield and overall efficiency during the entire lactation period. Therefore, there is no doubt that one of the main objectives during the peripartum period is to reduce infections, tissue damages and inflammation.

Dry period management may play a key role in minimizing health problems, including causes of cytokine release. Among the non-feed related approaches, hygiene and prophylaxis (vaccines, de-worming treatments, adequate mastitis treatments, hoof trimming, etc.), reduction of dystocia (i.e. small calve sires), and reduction of any kind of stress in the last stage of pregnancy (and mostly at calving time) play an important role. Nevertheless, a proper feeding management also makes it possible to maximize immune system capacity through an appropriate supply of nutrients. Furthermore, it can also prevent metabolic and digestive diseases, (milk fever, retained placenta, rumen acidosis, etc.) which occur more frequently around calving. According to our experience, the proper diet for the last 40–50 days of pregnancy would include:

- "low" energy concentration (1.25 Mcal of NEl/kg of dry matter);
- acceptable crude protein concentration (12–13 percent dry matter);
- high fibre (effective) content;
- "low" Ca and P (as well as Na and K) and high Mg contents for milk fever prevention;
- good trace elements and vitamin supply; special attention is needed for the anti-oxidative systems based on nutraceuticals (for example vitamin E, ß-carotene and polyphenols) which must be available in proper amounts; the adequacy of minerals such as Cu, Se and Mn is also required because the activities of peroxide scavenging enzymatic systems such as superoxide dismutase, paraoxonase and glutathione peroxidase are linked to them.
- high energy diet during the close-up period (days before calving) may be avoided; if applied, it must be short (8–10 days) and light (2–3 kg/day of concentrate).

INFLAMMATION MODULATION

Nevertheless, it seems unrealistic to expect an elimination of any inflammatory process. Therefore, it also seems advisable to modulate the inflammation phenomenon *per se* and to attenuate the systemic response to it. Today, there are several possibilities for modulating this process, such as some common anti-inflammatory drugs formerly derived from plants (e.g. acetylsalicylic acid). Some polyunsaturated fatty acids (PUFA), such as omega-3 and conjugated linoleic acid (CLA), have also been found to be effective. Lately, attention is being paid to some common and exotic plants (herbs), which are characterized by anti-inflammatory or immune-stimulatory properties, and consequently might be used as nutraceuticals.

Acetylsalicylic acid (ASA). The intramuscular administration of 15 g/day of ASA, the most popular anti-inflammatory molecule, for three-four days after calving reduced the incidence of clinical disorders and the severity of the inflammatory response. Furthermore, positive effects are exerted on both milk yield and fertility (Trevisi and Bertoni, 2008).

Omega-3 fatty acids (ω-3). These fatty acids have been well known as anti-inflammatory nutrients in humans since 1980 and Bertoni *et al.* (2006) showed that their levels in blood markedly decrease around calving. In order to keep a high plasma level, some experiments based on the oral administration of ω-3 from different sources (algae or fish oil) were carried out. All the products were rumen-protected and rich in eicosapentaenoic and docosahexaenoic acids. The administration, either alone (16.4 g/cow/day of ω3 from fish oil; Bertoni *et al*., 2006) or in combination with vitamin E (18.5 g/cow/day of ω3 from algae-extract; Trevisi *et al*., 2011b), during the peripartum increased plasma concentrations of ω-3. All cows involved in the experiments (fed ω-3 or non-treated) suffered an enhanced inflammatory condition immediately after calving, highlighted by the rise of positive acute phase proteins. However, the cows fed ω-3 were able to recover better, as confirmed by a quicker recovery of the negative (albumin, lipoproteins) and by the fast reduction of the positive (haptoglobin) acute phase proteins after calving. Interestingly, ω-3 administration also exerted a positive effect on the energy metabolism.

Conjugated linoleic acid (CLA). This fatty acid is known to reduce milk fat content in dairy cows and to attenuate inflammatory phenomena in animals. To confirm the latter effect on dairy cows during their transition period, we administered 20 g of a mixture of CLA isomers (50 percent of c9t11 and 50 percent of t10c12 protected from rumen) from 28 days before calving to 28 days in milk. The CLA administration determined an attenuation of the inflammatory consequences after calving, as suggested by the lower rectal temperature and by the quicker raising or recovery of some negative acute phase proteins (improved liver synthesis). Moreover, CLA treatment was able to reduce the negative energy balance, as confirmed by several indices showing an increased energy availability (increased feed intake and plasma glucose) and a reduced energy expenditure (slightly lower milk yield and fat content, lower NEFA and BHB in plasma).

CONCLUSION

Nutrient deficiencies (and excesses) can be responsible for metabolic and infectious diseases, and thus for animal welfare impairment, and overall may result in poor efficiency and income for the farm. In high yielding cows in particular, this occurs more often during the transition period and the inadequate increase of dry matter intake can be an important causal factor. Nevertheless, low dry matter intake can also be a consequence of health disorders that induce inflammatory conditions (such as metritis, mastitis, lameness, etc.) through the release of pro-inflammatory cytokines. Some surveys on the transition period of dairy cows showed a relatively high frequency of inflammations, mostly subclinical, which besides infections could be justified in several ways: tissue damages, oxidative stress, digestive upsets, heat stress, placenta-uterus interactions, dystocia, excess of energy supply, etc. To avoid inflammatory phenomena to the greatest extent possible, it is recommended to take advantage of the dry period to prevent infectious and metabolic diseases, as well as any other cause of pro-inflammatory cytokine release in the postpartum. Furthermore, it appears possible to reduce the consequences of inflammatory events by using specific drugs as well as some nutrients or nutraceutical substances (such as some long-chain unsaturated fatty acids). This can have relevant economic consequences because it appears that low inflammation during the transition period is associated with improved milk yield, low incidence of health problems and improved fertility, hence improved efficiency and animal welfare.

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Animal welfare includes the combination of both physical and mental well-being. A properly balanced diet and water supplied in adequate amounts avoid physical and psychological suffering from hunger and thirst; furthermore correct nutrition is crucial for optimal performance and to sustain optimal fitness. So far little attention has been paid to understand the linkages between animal nutrition and animal welfare. Farmers find it difficult to adopt practices that promote animal welfare without having sound information on the impact of such practices on animal productivity and their income. This AGA Paper presents a series of case studies to document existing practices that enhance animal welfare as well as farmers' incomes. It is hoped that the information contained will encourage researchers and agencies working in the area of animal welfare to initiate studies to capture the impact of any intervention on farmers' incomes – an area that has been neglected to date. It is also envisaged that these studies could pave the way for developing guidelines and policy options to promote sustainable animal feeding that enhances animal welfare, animal productivity, animal product quality and profitability.

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