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Assessing the diversity of trade-offs between life functions in early lactation dairy cows

E. Ollion[a,b,c,g,*], S. Ingrand[b], L. Delaby[d], J.M. Trommenschlager[e], S. Colette-Leurent[f], F. Blanc[a,c]

[a] INRA, UMR1213 Herbivores, F-63122 Saint-Genès-Champanelle, France
[b] INRA département Phase, UMR1273 Métafort, F-63122 Saint-Genès-Champanelle, France
[c] Clermont Université, VetAgro Sup, BP 10448, F-63000 Clermont-Ferrand, France
[d] INRA, AgroCampus Ouest, UMR1348 Pegase, F-35590 Saint-Gilles, France
[e] INRA, UR-ASTER, F-88500 Mirecourt, France
[f] INRA, UE 0326, Domaine Expérimental du Pin-au-Haras, Borculo, F-61310 Exmes, France
[g] ISARA-Lyon, département AGE, F-63364 Lyon, France

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ABSTRACT

This study objective was to develop a method to characterize the diversity of trade-offs between life functions expressed by dairy cows. Trade-offs between life functions involve adaptive responses of dairy cows to suboptimal nutritional environments. Until now, they have been explored mainly by examining unfavorable correlations between two traits. These two-trait approaches are limiting for exploring the diversity of trade-offs among cows. A multi-trait and dynamic method was developed to phenotype trade-offs between life functions involved in cow fitness (lactation, reproduction, and ability to survive) and explore their diversity. Records from 334 lactating cows reared in two experimental INRA (France) units were used to study the dynamics of cow milk yield, body condition changes and reproduction performance. The analysis focused on the first 13 weeks postpartum, when cows are supposed to experience a negative energy balance. Ten variables accounting for the dynamics of responses were calculated and included in a clustering analysis. Four main clusters of trade-offs were obtained. Profile 1 of trade-off ($N=53$) included cows giving priority to lactation and mobilizing much of their body fat reserves, with poor reproductive performance. Trade-off profile 2 ($N=111$) identified cows mobilizing much of their body fat reserves, giving priority to reproduction at the expense of high milk yield. Trade-off profile 3 ($N=67$) consisted of thin cows presenting difficulties in all functions: a large body-reserve mobilization after calving that does not benefit to milk yield and long delays before reproducing and low success rates. Profile 4 of trade-off ($N=103$) was composed of cows with no trade-off between functions, since they recorded average milk yield, maintained their body condition and had good reproductive performances. Our approach highlighted the relevance of considering the three life functions simultaneously when phenotyping dairy cows for their ability to manage prioritization between life functions and this multi-trait clustering approach represents an operational tool to do so, using readily available farm data. Since classification of cows into clusters is not fully determined by the breed or parity, our study underlined also the utility of better understanding the mechanisms that drive nutrient allocation between life functions. We also believe in the benefit of considering this individual diversity, as a herd management tool for farmers.

1. Introduction

In ecology, trade-offs represent unfavorable associations that exist between life history functions (Zera and Harshman, 2001). Trade-offs result from the expression of genetically driven mechanisms (Roff et al., 2002) that ensure the fitness of animals when resources are limited (Blanc et al., 2006). They result from priority rules for nutrient allocation implemented in limited environments, i.e. in situations in which the pool of available nutrients (intake and body mobilization) do not meet the energy demand for life functions (Glazier, 2009). In animal science, the term “trade-offs” is generally used to describe the expression of

* Correspondence to: ISARA-Lyon, 23 rue Jean Baldassini, 69364 Lyon Cedex 07, France.
E-mail address: eollion@isara.fr (E. Ollion).

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unfavorable genetic correlations (Windig et al., 2006) observed between production traits accounting for physiological functions (e.g. growth, lactation, and reproduction) in constraining environments. In most literature on dairy cows, trade-offs were mainly explored by studying the expression of unfavorable genetic associations between only two traits (Hoekstra et al., 1994, Pryce et al., 1997). However, several studies reported that high-yielding dairy cows exhibit trade-offs between several functions: milk production, growth and reproduction during energy-restricted situations, such as during early lactation (Friggens et al., 2010). When animals selected for milk production have a negative energy balance (**NEB**) (Gross et al., 2011), nutrient partitioning is genetically driven toward lactation to the detriment of other functions such as reproduction (Friggens and Newbold, 2007, Friggens et al., 2013).

We considered that the main functions of interest in dairy cows are lactation, reproduction, and the ability to cope with external stressors and survive. The first two functions can be studied through milk production records and reproductive traits (time of conception, pregnancy success rate, etc.). The last function is most difficult to ascertain with direct traits or indicators because the cow lifespan strongly depends on the culling rules defined by the farmer. Furthermore, giving such an assessment would imply having indications on health, well-being status and metabolic capacities to cope with stressors. Body condition score (**BCS**) is an assessment of animal fat reserves and provides an estimate of body-reserve mobilization when a cow is in NEB (Roche et al., 2009). BCS changes give information about the flexibility provided by body fat reserves to adapt to and buffer against nutritional changes (Gearhart et al., 1990, Friggens, 2003). BCS can also be an indirect indicator of animal health when frequently assessed (Berry et al., 2008) and provides relative information about cow welfare (Roche et al., 2009). In addition, BCS is easily measurable on farm at low cost. Therefore, BCS could be considered an acceptable indicator to evaluate the ability of dairy cows to cope with external stressors and survive in restricted nutritional environments.

Several studies approached trade-offs in dairy cows through experiments that included nutritional challenges and separately compared milk yield, BCS and reproduction responses (Dillon et al., 2003, Horn et al., 2014). In these previously mentioned studies, performances and trade-offs expressed by dairy cows were analyzed separately by breed and parity, assuming that breed and parity are significant drivers of trade-offs. To move beyond this hypothesis, we investigated trade-offs independently from individual cow characteristics and used them a posteriori as potential explicative factors for the diversity of trade-offs expressed by dairy cows.

As suggested by Friggens and Newbold (2007) and Friggens and Van der Waaij (2009), we make the hypothesis that trade-offs between physiological functions should be studied through a multi-trait approach. We also hypothesize that trade-offs should be studied with dynamic rather than static approaches to investigate biological response changes over time (Roff et al., 2002) and use short-time-step analysis (Friggens and Van der Waaij, 2009). This study objective is to characterize trade-offs diversity in dairy cows by using a multi-trait clustering approach jointly analyzing the dynamics of the three main life functions: lactation, reproduction and the ability to adapt and survive.

2. Material and methods

2.1. Data

This study is based on analyzing data from dairy cows enrolled in three long-term experiments conducted at two INRA (France) experimental units. Cows at both sites were housed during winter and grazed for the rest of the year. The first experiment was conducted on the Mirecourt farm (48.3°N, 6.13°E) in northeastern France from 2000 to 2003 with Holstein and Montbéliarde cows reared as one herd in a conventional system and fed forage (maize and grass silage) ad libitum and 4 kg/cow/d of concentrates (barley and protein meal). Cows in this system were part of the Mirecourt High Energy Diet group (**M-HED**). The second experiment was conducted from 2004 to 2012 at the Mirecourt experimental dairy farm, also with Holstein and Montbéliarde cows. Two organic systems were designed for the experiment: a Grass-based System (**M-GS**) and a Mixed-crop dairy System (**M-MS**), as described by Gouttenoire et al. (2010) and Coquil et al. (2014). Cows from the M-GS were fed only forage (grass and hay) with maximum grazing achieved by grouping the calving season over a three-month period in late winter. Cows enrolled in the M-MS calved over a three-month period in autumn and were fed 2–4 kg of concentrates (barley or oats and peas or lupine) and forage (90% hay and 10% silage or haylage). The third experiment was conducted on the Le Pin-au-Haras (48.4°N, 0.09°E) experimental dairy farm in northwestern France from 2006 to 2011 with both Normande and Holstein cows. In this experiment, cows were equally distributed in two herds that were fed two different diets, as described by Cutullic et al. (2011). The first diet, characterized by a Low Energy Diet (**L-LED**), was based only on forage with a winter total mixed ration of 50% grass silage and 50% haylage and a spring-to-autumn ration exclusively based on grazing. The L-LED reproduction period was restricted from April to June to synchronize the cows' energy requirements with grass growth. The second group, characterized by a High Energy Diet (**L-HED**), received a total mixed ration in winter composed of 55% maize silage, 15% dehydrated alfalfa and 30% concentrates, and a spring to autumn diet based on grazing supplemented with 4 kg of concentrates/cow/d and 5–8 kg of maize silage/cow/d if a significant drop in grass growth was observed. Cow drying-off and reproductive management followed common rules in both experimental units to keep calvings grouped within a 91 d target period. Cows were dried-off 60 d before presume calving date and fed grass silage. Cows with BCS >2, three months before calving were dried-off earlier. Calendar-based starting and ending dates for the breeding season were defined each year within each experiment to keep calvings grouped within a 91 d target period. The starting date was either the herd starting date of the breeding season for cows calved at least 42 d before this calendar date or the calving date of the cow plus 42 d for cows calving after the herd calendar starting date. Thus, all animals were given at least 42 d between calving and first service, but the length of the breeding season differed for each cow according to its previous calving date. Cows were inseminated at natural estruses when observed from their starting date to the ending date of the breeding season. Consequently, the length of the breeding season differed for each cow, with a maximum of 13 weeks. In all experiments, each cow was monitored for milk production, body condition, and reproductive and health events. The dataset for each cow included: weekly milk records; BCS, scale 0 = thin to 5 = fat (Agabriel et al., 1986); breeding events: calving date, service dates, conception date; and individual information: date of birth, lactation rank, breed, and age at calving. BCS was recorded at calving and at least every month postpartum. Lactations with abnormal milk-yield values, i.e. when a recorded milk yield was less than 50% of the previously recorded milk yield (Wiggans et al., 2003), were fully excluded from the dataset. Similarly, extended lactations of more than 525 d, as defined by Grossman and Koops (2003), were removed from the dataset. Cows included in the dataset produced an average of 6035 ± 1695 kg of milk per lactation (Table 1). The average