Precision Feeding to Increase Efficiency for Milk Production

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■ Take Home Messages

- Precision technologies only work when the other key aspects of a dairy herd work as they provide a marginal advantage but not a total solution.
- A "balanced" mouthful of a total mixed ration (TMR) for one cow may be an "imbalanced" mouthful for another cow, or even a "balanced" mouthful of a TMR for one cow in early lactation may become an "imbalanced" mouthful in the same cow in mid or late lactation.
- Precision feeding of cows can be of special importance herds with less than 300-500 cows that cannot fully benefit from economies of scale.
- Dynamic concentrate parlor feeders (DCPF) allow preparation and delivery of as many different feeds (in both quantity and composition) as number of cows are milked in a parlor.
- The advantages of DCPF is that a relatively inexpensive TMR can be fed to all cows, and then only those needing more nutrients and able to "pay" for them receive the necessary supplements during milking.

■ Introduction

Traditionally, dairy cows were offered concentrates in the milking parlor. However, with the introduction of total mixed rations (TMR), feeding in the milking parlor has been progressively abandoned. The introduction of TMRs represented a revolution in feeding and managing of dairy cows. TMRs have simplified and automated the feeding of cows and have allowed for substantial increases in milk production. However, feeding TMRs has some limitations. Technically, the nutritionist designs one ration for a "reference cow" but obviously not all cows that receive the formulated TMR will fit the description of the "reference cow", and thus some cows in the group will receive more and some others less nutrients than they actually need. In an attempt to minimize these deviations some alternatives were introduced in the 80's such as automatic concentrate feeders, manual top-dressing of close-up cows, or feeding in the parlor. Over time, most operations substituted feeding in the parlor with supplementing cows fed TMRs using automatic concentrate feeders. This technology provides incremental feed to specific cows that, theoretically, were not meeting their nutrient needs from the TMR alone. However, the use of automatic concentrate feeders has also been progressively abandoned in most dairy production systems. Ironically, one the most modern (not necessarily the most advantageous) technologies, automatic milking systems (AMS), relies heavily on supplementing cows a fixed-formulated concentrate (sometimes the systems can handle different feed types) to motivate cows to visit the AMS and minimize the number of cows that need to be fetched (Bach et al., 2007). With AMS, feeding during milking is a necessity rather than a nutritional strategy.

On the other hand, most pasture systems have not abandoned feeding in the milking parlor, and recently, in South Africa and New Zealand in particular, parlors equipped with a rotary have embraced a novel technology that allows mixing of two different feeds and offers a "customized" formula to each cow in the parlor based on individual level of milk production and in some instances body weight changes.

Most outlooks indicate that by 2050 food production will have to double from current figures (Foley, 2011). This increased demand will have to be mainly driven by improved efficiency, as the amount of natural resources available is not likely to increase. Also, it is anticipated that feed cost for dairy cattle will continue to rise due to increased prices of feedstuffs. In the last 3 years, for instance, most of the world has seen and struggled with prices for corn or soybean meal that have almost doubled (although nowadays corn prices have come down substantially). Interestingly, despite these drastic changes in feed prices, global milk price has not changed much, and even more interestingly, the way producers have been feeding dairy herds has also undergone very minor changes.

This article presents a new precision feeding system for rotary parlors aimed at maximizing milk efficiency of dairy cattle and minimizing detrimental effects on natural resources and the environment. The advantages and disadvantages of such a system will be discussed and compared with more traditional feeding methods.

With the introduction of milking equipment able to measure (with more or less accuracy) milk components such as fat and protein, in addition to milk volume, producers can now determine the nutrient requirements of each cow with much more precision. These advances have led to the appearance of the system presented herein, which we call the dynamic concentrate parlor feeder (DCPF). The DCPF is a conglomerate of technologies aimed at taking advantage of precision dairy feeding to maximize the efficiency of utilization of natural resources and the economic returns of dairy herds. The system consists of a rotary parlor equipped with radiofrequency identification, electronic milk meters, on-line meters for fat and protein content in milk, an electronic scale to determine body weight (BW) of the cow, and a state-of-the-art feed mill able to mix six different ingredients and deliver the mixed feeds to the parlor in less than 14 seconds. Thus, this equipment allows the producer to prepare and deliver as many different feeds (in both quantity and composition) as number of cows milked in the parlor. The DCPF calculates the individual nutritional needs of each cow as she enters the rotary based on her assigned feed intake (average of the pen where she is; although it can also use the actual individual intake where individual feeders are available), composition of the TMR fed, stage of lactation, parity, BW, BW change, days pregnant, milk yield, and milk component yields, and then creates a least-cost formula using the six feeds which are mixed and delivered to the cow onto a feeding manger in the parlor (all this in <14 seconds). Then, the cow has about 10 minutes to consume the feed. Last, as the cow leaves the carousel, the feed manger is cleaned with water and becomes ready for the next cow entering the rotary.

▪ Nutritional Considerations

Feeding a TMR offers the great advantage of simplicity as it allows feeding large numbers of cows in groups. In addition, theoretically, with TMRs, each mouthful of feed the cow consumes contains a balanced combination of nutrients. However, because cows do sort (Mulfair et al., 2010), the composition of the TMR actually changes throughout the day and the balanced nutrient profile may become imbalanced. Furthermore, cows need to consume balanced meals of nutrients of optimal size. In other words, because intake is variable between cows and also within cows depending on stage of lactation, BW, and other factors, a “balanced” mouthful of a TMR for one cow may be an “imbalanced” mouthful for another cow, or even a “balanced” mouthful of a TMR for one cow in early lactation may become an “imbalanced” mouthful for the same cow in mid or late lactation. For example, according to the NRC (2001), a cow producing 27 kg of milk per day needs 29.5 Mcal of net energy of lactation (NEl) and about 3.2 kg of crude protein (CP) or 1.95 kg/d of metabolizable protein each day. A cow with such a level of milk production would consume 20.6 kg of DM/day, thus the TMR should have a nutrient density of 1.44 Mcal of NEl/kg and 15.4% CP or 9.5% metabolizable protein (DM basis). If that same TMR was consumed by a cow producing 30 kg of milk per day, according to NRC (2001), dry matter intake would increase by 1 kg and she would need an additional 2 Mcal of NEl and 103 g of additional metabolizable protein. If she consumes 21.6 kg of the TMR balanced for 27 kg of milk per day she would consume 1.42 additional Mcal (while needing 2 additional Mcal) and 35 additional grams of metabolizable protein (while needing an additional 103 g). Thus energy and protein consumption progressively lags behind needs at different proportions as milk production increases if the cow continues to eat a TMR with the same nutrient profile (Figure 1). Thus, within a group of cows consuming the same TMR, the more that milk yield of a cow deviates from the level used to formulate the TMR, the more each mouthful of TMR deviates from the nutrient requirement of the cow.

Similarly to what occurs with TMRs, automatic concentrate feeders typically offer a feed with a fixed chemical and nutritional composition with the only variable in the system being the amount of feed that each cow is entailed to consume on a daily basis. Thus, depending on the nutrient density of the basal TMR, the stage of lactation and milk production, cows receive different amounts of feed, but as with a TMR, the composition of the pellet or mash offered is the same regardless of the level of milk production, and thus also progressively becoming imbalanced as milk yield deviates from the one used to formulate the feed supplement. An additional shortcoming of an automatic feeder is that although this system may offer some nutritional advantages because it can provide more nutrients to the cows with greater needs, the algorithm used to determine nutrient requirements is based only on milk yield, without accounting for 1) the energy and protein content of milk (milk components) and 2) BW changes.

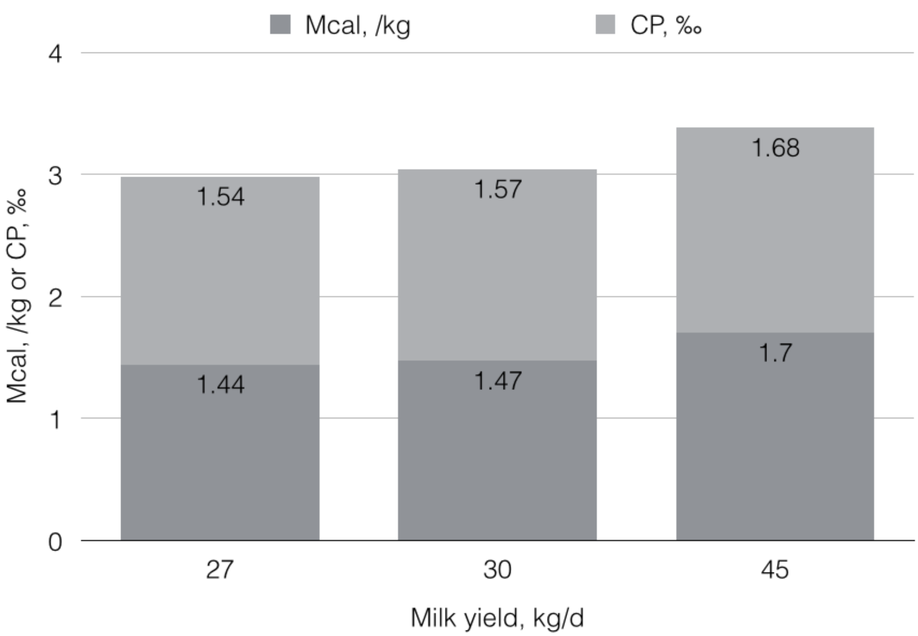

Figure 1. Evolution of energy and protein concentration (Mcal and %, respectively) needed in the dry feed consumed by cows as affected by level of milk production according to NRC (2001).

The DCPF uses an algorithm to calculate the nutrient needs of each cow that accounts not only for milk production, but also for milk composition as well as BW (and changes in BW) to determine nutrient needs. The advantage of the DCPF is that it formulates a mix of six different ingredients and delivers different amounts of each, thereby satisfying the varying nutrient demands of cows as their level of dry matter intake, milk, and milk components change. As an example, Figure 2 shows the evolution of chemical and nutrient composition of a concentrate that would be delivered in the parlor to cows consuming the same basal TMR but producing different levels of milk.

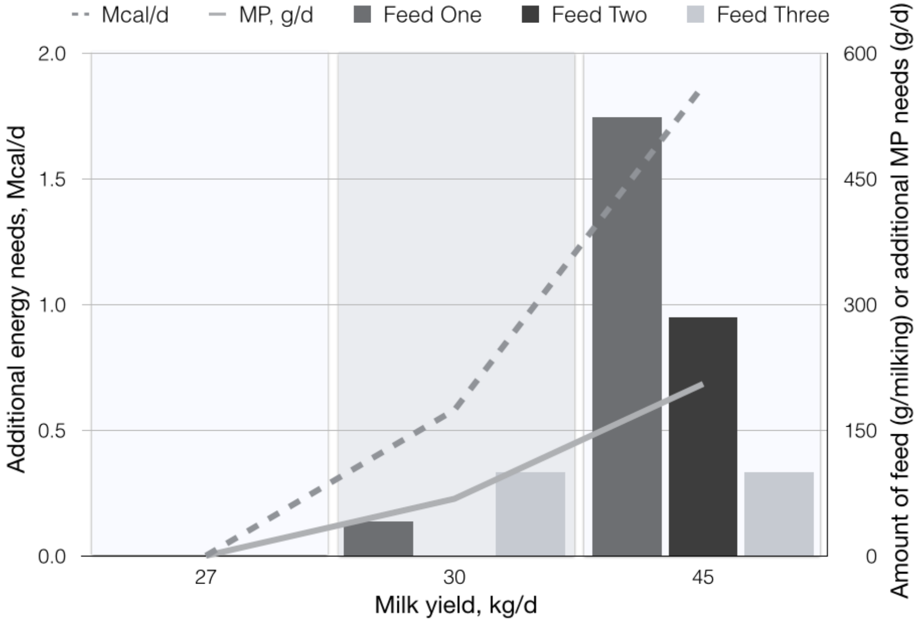

Figure 2. Amount of three different ingredients (feed one, two, and three) that should be mixed and delivered to a milking parlor three times a day depending on the additional energy and protein requirements of cows fed a common TMR as the level of milk produced increases. The common TMR provides sufficient nutrients to support 27 kg/d of milk yield, thus no additional feeds are needed. At 30 kg/d of milk yield, feeds one and three are needed. At 45 kg/d of milk yield, all three feeds are needed.

The use of precision feeding with a DCPF involves deciding how often data should be collected and summarized and how often data should be used to estimate requirements of cows. Milk production within a cow typically has daily coefficient of variations of 6-8%, those for milk components range between 2 and 3%, and those of BW are about 3-4% depending on stage of lactation. In the two DCPFs that we have been monitoring, algorithms to calculate nutrient needs have been derived using 10-d smoothed weighted rolling averages of data collected at each milking and summarized daily.

Potential caveats with precision feeding technologies include that cows, despite their theoretical needs for nutrients, may opt to not consume the amount of feed allocated to them. In the automatic concentrate feeders and AMS that represents a lost opportunity. With the DCPF, this type of situation represents both a lost opportunity and a loss of feed and money (once the cow is identified and the amount of feed is calculated and dispensed, any unconsumed feed is discarded at the end of the milking). However, in our experience DCPF systems differ from AMS and automatic concentrate feeders (where cows visit the feeding stations at different hours of the day and at varying intervals) in terms of feeding behaviour of cows. With the DCPF, cows are consistently fed at the same times and intervals each day (fixed milking times), and this may explain why there are minimal refusals of feed in the parlor (at least when feeding up to 1.5 kg per milking).

▪ Management Considerations

In the last years, a progressive increase in the implementation of several precision farming technologies (AMS, automatic calf feeders, pedometers, etc.) has taken place. Although the application of these technologies has resulted in improvements in production and profitability, in some instances the advantages that these systems offer have been limited by an excessive focus around aspects inherent to precision technology at the expense of understanding pivotal and basic aspects of dairy production, such as adequate TMR mixing, accurate monitoring of moisture and nutrient content of feeds, stocking density, feed bunk management, etc. For instance, Cook (2008) reported that about 30% of the variation in dry matter intake could be explained by dietary factors, with the remaining 70% being attributed to non-dietary factors. Similarly, Bach et al. (2008) reported that key management aspects such as age at first calving, amount of feed refusals, number of feed push ups, and stocking density explained more than 55% of the variation in milk production observed in 47 herds that were feeding exactly the same TMR. Therefore, if a herd has a management problem, the adoption of precision technologies will not solve it. Furthermore, some precision technologies alter herd dynamics and their implementation requires special attention and excellent management. For example, with automatic feeders, cows need to attend the feeder individually, which is an unnatural behavior. Dairy cows (and cattle in general) are gregarious and show marked synchronized behaviors (Benham, 1992). Automatic feeders may also elicit some disputes between cows to access the feed and diminish lying times of both types of cows: those that engage in conflicts and those cows that peacefully wait to access the feeder. Furthermore, the areas around the automatic feeders tend to become dirtier than the rest of the barn due to an increased concentration of animals lining up to access the feed. The AMS poses the same challenge as the automatic feeders regarding the fact that cows need to disrupt the synchrony of the herd behavior and attend the AMS on an individual basis. The additional problem of the AMS is that if attendance decreases, udder health and animal welfare may be compromised in addition to milk production. An important difference between the DCPF, and other systems that provide feed in the milking parlor, including the AMS, is that it causes no social disruption of the herd, as all cows in the same group are fed, milked (and re-fed) at the same times and as a group. However, when using DCPF we have noticed that if only some cows receive feed in the parlor, those that get offered no feed are more nervous and look for feed. To overcome this problem, it is recommended that cows that do not need supplement be fed about 100 g of an inexpensive feed (i.e. soybean hulls) while milking.

Lastly, another relevant management aspect is the quality and consistency of TMR mixes. When feeding different TMRs to different groups of cows, consultants and producers should take into account the difficulties and challenges involved with preparing a good TMR. A good example of this challenge is splitting dry cows in far-off and close-up groups. In small herds (< 200 cows) splitting dry cows in 2 groups may require preparing TMRs for less than 15 animals, which easily leads to large mixing errors (the less TMR prepared the greater the weighing errors). Using automatic feeders of DCPF facilitates feeding a single TMR and then providing additional nutrients to specific cows within each group.

▪ Economic Considerations

In many occasions, especially in large herds, cows are grouped according to production level, and fed different TMRs with various nutrient densities. The aim of feeding different TMRs according to production is to improve income of over feed cost (IOFC) by feeding less expensive rations to low-producing cows (mid or late lactation). However, because milk price is much greater than feed price, feeding different TMRs according to the level of milk production will only prove profitable if the savings in feed cost overcome the losses associated with a reduction in milk production that cows will experience when moved from a high- to a low-producing pen. A loss in milk production could be expected when changing cows between groups due to 1) consumption of a less nutrient-dense ration, and 2) diversion of some the available energy to cope with the change of environment (social disruption). Back in the 70's, it had been already reported that cows would decrease milk production when moved across pens (Coppock, 1977), and more recently, Guasch and Bach (2009) reported that lying times (min/d) of cows that were moved in groups from one pen to another (keeping nutrition, stocking density, management, and cubicle design the same) was reduced by 12% (about 70 minutes) during the first week after pen movement, and continued to be 8% lower 4 weeks after pen movement. However, in some occasions, feeding different TMRs may prove economically advantageous, even when they represent an economic loss due to the differential between feed savings and milk loses. This is the case when cows on a single TMR gain excessive body condition, which will impair milk production (and perhaps longevity and reproductive performance) in the next lactation. Thus, it is important that feeding decisions are made considering the entire production system and the long-term consequences of the implemented changes. The use of automatic feeders allows minimizing milk losses due to pen movements and dilution of the TMR as lactation progresses. Bath and Sosnik (1992) observed the highest feed efficiency from feeding cows individually based on size and milk production.

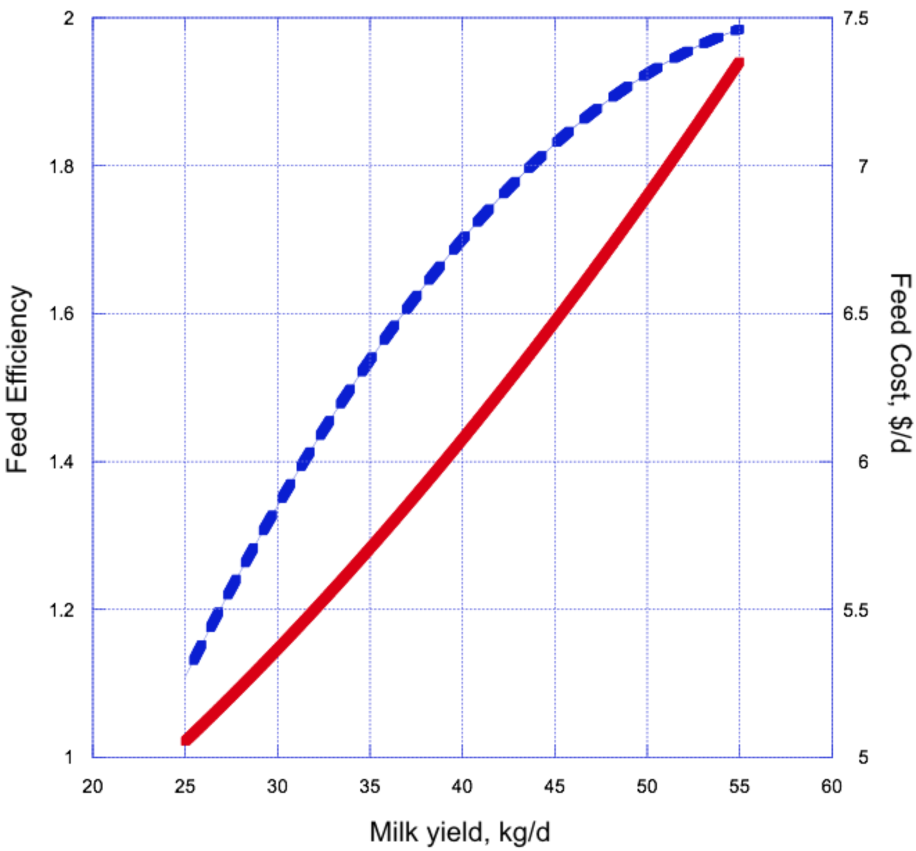

Figure 3. Evolution of feed efficiency (kg of milk/kg of dry matter intake; dotted line) and feed costs ($/d; solid line) as affected by milk yield.

In the last years, feed prices have experienced a continuous and drastic increase while milk prices have remained relatively stable. This situation has shrunk margins and benefits for producers. Large enterprises have relied on economies of scale to overcome the situation, whereas small enterprises or those with little possibilities of expansion have had to rely on improved efficiency of nutrient conversion into milk. Under this context, precision feeding of cows can be of particular importance for herds with less than 500 cows that cannot fully benefit from economies of scale compared with larger herds. There are two main ways to improve profit: 1) reducing feed costs while maintaining or losing very little milk, or 2) increasing feed cost and improving milk yield in an amount whereby revenue offsets the investment in feed.

A key aspect that affects profit and needs to be understood is how feed efficiency and feed prices evolve as milk production increases. In this regard, the first question to ask is whether the law of diminishing returns (adding more of one factor of production, while holding all others constant, will at some point yield lower per-unit returns) applies to milk production. Traditionally, it has been thought that improvements in yield dilute maintenance needs and thus efficiency increases. But the issue resides in determining whether the increase in efficiency is linear or whether it follows a diminishing returns pattern. Figure 3 (dotted line) shows that indeed, as milk yield increases, feed efficiency increases, but for each additional increase in milk yield, the increase in efficiency becomes smaller. On the other hand, the same Figure 3 (solid line) shows a curvilinear increase in feed costs as milk yield increases. The combination of the solid and the dotted lines in Figure 3 dictates how margin evolves in dairy herds. Indeed, the law of diminishing returns does apply to dairy cattle, and as milk yield increases the marginal return on the investment decreases.

■ Combining Nutrition And Economics

Considering the evolution of feed efficiency with milk yield, and the trend for feed costs, implementing alternatives to improve feed efficiency (or at least considering feed efficiency within the herd) may prove profitable. Just as an example, dairy cows convert dietary protein to milk protein with an efficiency that ranges between 22 and 38% (Bach et al., 2006). When soybean meal was priced at US $200/tonne and milk priced at $0.32/liter, assuming an efficiency of conversion of dietary protein to milk protein of 28%, 1 kg of soybean meal would yield an IOFC of about US $1.03. With current market situations, with soybean meal at US $550/tonne and the same milk price, every kg of soybean meal generates an IOFC of US $0.68. If the efficiency of protein utilization was 25 instead of 28%, then the IOFC would be US $0.55. Indeed, feeding soybean meal still provides some marginal return, but it is almost half of what it used to be. Thus, producers who have continued to feed following the same nutritional scheme have incurred a great loss of margin. Under this scenario, producers and nutritionists should think twice about the return on feed investment. Cabrera et al. (2009) proposed that an effective way to improve IOFC is by making different TMRs according to milk production, but they also reported that formulating a concentrate to provide to specific cows consuming a single TMR was even more economically advantageous. This would be a similar strategy as using a DCPF. The advantages of DCPF is that a relatively inexpensive TMR can be fed to all cows, and then only those needing more nutrients and being able to "pay" for them in terms of high milk yields receive the necessary nutrients during milking.

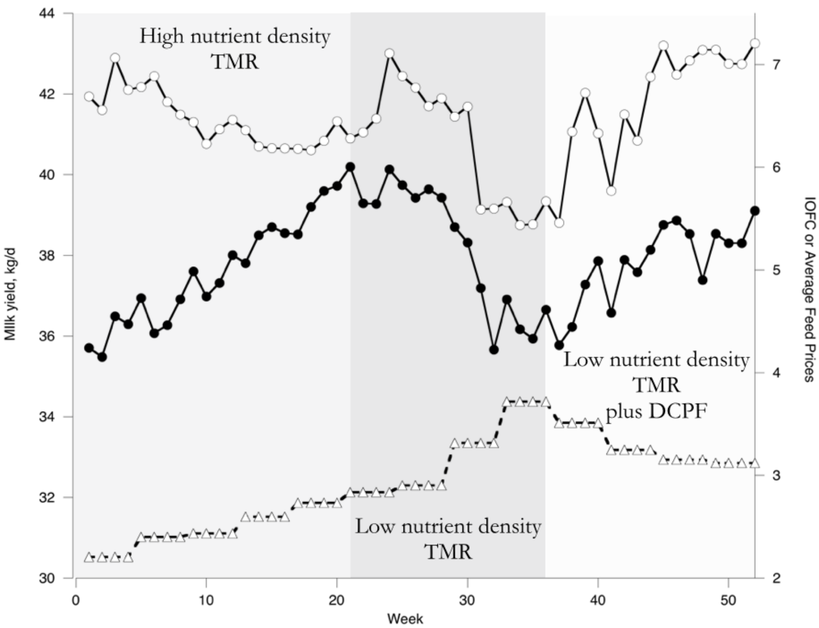

Figure 4. Evolution of milk yield (open circles), feed prices open triangles), and income over feed cost (solid circles) across all 52 weeks of the year 2012 for a group of 120 cows. On week 21, feed costs were drastically reduced by decreasing nutrient density of the TMR, and on week 35 cows continued on the same low density TMR but were supplemented using a DCPF.

The DCPF utilizes an algorithm that not only ensures the provision of the nutrients required by each cow but it also makes sure that the expected improvement in milk yield will pay for the additional feeding cost for each particular animal. In other words, if a given feed supplement for a given cow costs 0.32 US$/day and the expected increase in yield is 1 kg (equivalent to 32 cents), then that cow would not be supplemented. Thus, using a DCPF system leads to a drastic reduction in feed costs by decreasing the nutrient density of the basal TMR as specific cows receive supplemental nutrients in the parlor. Figure 4 shows the milk yield responses after changing a group of 120 cows from a single TMR to low-nutrient density TMR on week 21, and then on week 35 supplementing cows on the low-nutrient density TMR using a DCPF. Despite the fact that the price of feed ingredients continued to increase after the change, feed costs were largely reduced, and despite the fact that there was a loss of milk yield, the savings in feed costs were greater than the losses in milk yield, and thus IOFC increased. The DCPF allowed maintaining similar IOFC (around 7 US$/day) in a situation where feed prices were 20% greater than before the implementation of the change.

Despite improvements in IOFC, the DCPF system needs to be further refined. Figure 5 compares performance of cows supplemented or not using a DCPF and kept within the same pen and fed the same TMR. Primiparous cows fed a basal TMR and supplemented using a DCPF responded well in milk production and IOFC. However, when comparing multiparous cows that received a TMR plus a small amount of concentrate in the parlor with multiparous cows that received the same TMR plus different amounts and types of concentrates using a DCPF, it was observed that milk yield improved with the DCPF, but IOFC did not improve as much as observed with primiparous cows. Research must be conducted to determine the factors that prevent further improvements of IOFC when using DCPF systems, especially with multiparous cows.

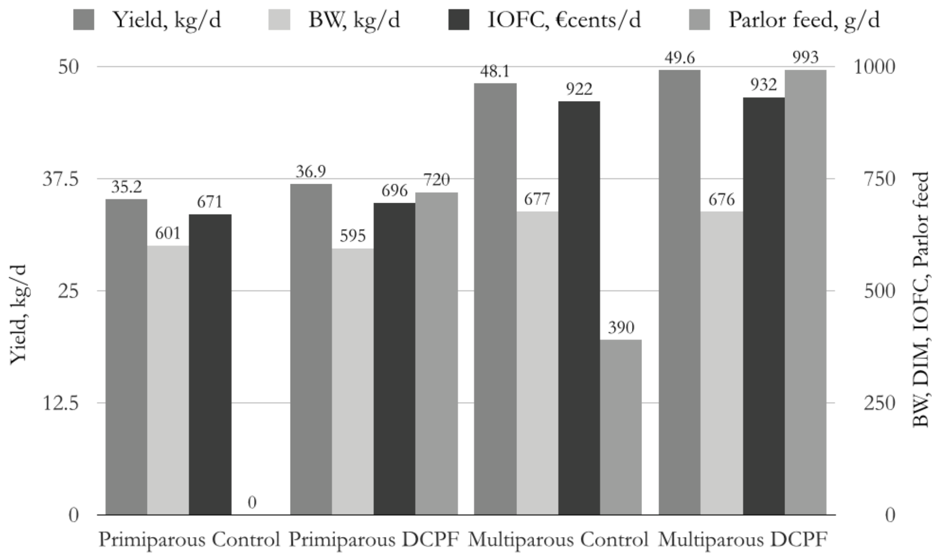

Figure 5. Milk yield, body weight (BW), and income over feed costs (IOFC) of primiparous and multiparous cows fed just a total mixed ration or cows fed a total mixed ration plus a supplement via a dynamic concentrate parlor feeder.

■ Concluding Remarks

When implementing precision technology on farm it is important to pay attention to basic aspects of dairy farming. In many occasions (automatic milking systems, automatic milk feeders, etc...) focus is placed in the new technology and basic and pivotal aspects such as ensuring that the mixing errors in total mixed rations are minimum, that the moisture content of feeds is measured (and accounted for) frequently, daily intake is monitored, etc... tend to be neglected. Precision technologies only work when the rest works, as they provide a marginal advantage but not a total solution.

Precision feeding using dynamic concentrate parlor feeders requires the right algorithms and cows need to adapt to the new feeding scheme and leave some room in their stomachs to consume the feed that will be delivered when visiting the parlor. A great advantage of dynamic concentrate parlor feeders is that they allow feeding a basal total mixed ration with a low nutrient density (and thus relatively inexpensive) without compromising (and even improving) income over feed cost thanks to delivery of customized concentrates in the parlor to only those cows that need them.

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