

## Individualised feeding of concentrate supplements to pasture-based dairy cows

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### ABSTRACT

The increasing availability and installation of computerised feeding and milk monitoring technology in Australia and New Zealand has led to an increased interest in feeding individual cows different amounts and types of supplements during milking. There is, however, confusion about the potential benefits of individualised feeding strategies compared with feeding the same amount of supplement to all cows in the herd. The majority of bail feeding research conducted over the past 30 years has identified little difference in cow response, between flat rate feeding and more complicated approaches of split feeding or feeding to individual cow milk yield. However, it must be noted that many of these experiments involved animals with unlimited access to a forage source. Large variability in response to supplements between individual cows within the herd implies there should be a benefit from individualised bail feeding practices. This review examines the potential for individualised bail feeding in pasture-based dairy systems, considering both system (pasture allowance) and cow level parameters (dry matter intake, milk yield, genotype, bodyweight etc.) that could affect the individual cow response to a particular supplement, and discusses the current limitations and future challenges for implementing this technology on farm. Recommendations for future research are made to address any knowledge gaps.

### INTRODUCTION

The majority of dairy farms in Australia and New Zealand are pasture-based. However, major limitations for cows in pasture-based systems include the seasonal variability in nutrient supply (Chapman *et al.* 2008, Chapman *et al.* 2009, Roche *et al.* 2009) and the fact that high producing cows cannot entirely satisfy their energy requirements from grazing alone (Kolver and Muller, 1998). Supplementation, with concentrates, is used to manage deficits in pasture supply (Holmes and Roche 2007) or to increase overall dry matter intake (DMI) and milk production (Stockdale, 2000, Bargo *et al.* 2003).

The predominant practice for farms feeding concentrate supplements to cows during milking is to provide the same quantity of feed to all cows. With the emergence and increasing uptake of modern feed and milk monitoring technology by dairy farmers for use in dairy sheds, there is increasing interest in the potential benefits of feeding each cow, according to individual nutritional requirements, with the aim of optimising production and maximising profitability. The shift in focus towards individualised management of cows is made possible with the introduction of electronic identification. As the ability to capture information about individual animals' increases, parameters such as milk yield and bodyweight can be easily collected and used as a basis for making feeding decisions.

According to a survey on Australian dairy farm technology and management practices conducted during 2010-11 (Dharma *et al.* 2012), approximately

15% of Australian dairy farms had computerised bail feeding systems with milk meters installed. In a 2013 survey of dairy farms in New Zealand (Edwards *et al.* 2014), 33% of farms were capable of feeding concentrates in the bail (up from 23% in 2008) and 22% of these feeding systems were capable of allocating one or more feed type simultaneously to individual cows. The most significant increase in feeding system installation has been associated with rotary dairies, with 62% having in-bail feeding systems (up from 43% in 2008) and 14% also having milk meters installed. In an on-line survey of 73 New Zealand farmers with computerised bail feeding systems, the main reasons provided for investing in the technology included the desire to improve productivity, reduce feed costs and better manage body condition score (BCS) (B. Dela Rue unpub. data). The combinations of milking/feeding systems are being used in many different ways by dairy farmers and their advisers to allocate grain/concentrates either to individuals or to groups within herds, rather than as a flat rate to all cows in the herd. The main parameters used by the surveyed New Zealand farmers to allocate feed on either an individual or group basis included milk yield (58%), breed and age (50%) bodyweight (42%), stage of pregnancy (40%) and BCS (37%) (B. Dela Rue unpub. data).

While the technology to enable individualised feeding is available and increasingly being installed on dairy farms, the value of individualised concentrate supplementation on production and farm profit remains unclear. The majority of bail

feeding research conducted over the past 30 years has identified little difference in cow response, between flat rate feeding and more complicated approaches of split feeding or feeding to individual cow milk yield (Bines, 1985; Leaver, 1988; Gill and Kaushal, 2000). Summarising the results of 7 trials comparing flat rate and stepped feeding strategies (Gordon 1982, Taylor and Leaver 1984, Poole 1987, Rijpkema *et al.* 1990, Aston *et al.* 1995) resulted in an average milk yield of 22.8 and 23 kg respectively and furthermore, the summary of 12 trials comparing between flat-rate and individualised feeding strategies, resulted in an average milk yield of 25.1 and 24.8 kg respectively (Gordon 1982, Taylor and Leaver 1984, Moisey and Leaver 1985, Taylor and Leaver 1986, Rijpkema *et al.* 1990). However, it must be noted that many of these experiments conducted during the past 30 years involved housed animals, with unlimited access to a forage source (in most cases high quality grass silage) in addition to the concentrate supplement. This is an important distinction as individual cows receiving high quality forage ad lib would be able to compensate, at least partially, for any shortage in concentrate. Conversely, in pasture-based systems most of the forage is offered as grazed pasture, typically restricted in quantity by grazing management and in quality by seasonality.

There have been very few comparisons of concentrate feeding methods in pasture-based grazing cows, particularly where there is restricted access to forage. Restricting pasture allowance results in increased pasture utilisation but also creates competition between cows for the available resource, inevitably, leading to variations in nutrient supply and demand, for individuals within a herd. Results of a recent study in Australia, where cows grazed restricted pasture allowances (Garcia *et al.* 2007), indicated cows fed a concentrate supplement, based upon individual requirements, produced 7% more fat and protein when compared with cows fed at a fixed rate based on overall herd requirement.

This review examines the potential for individualised bail feeding in pasture-based dairy systems, considering both system (pasture allowance) and cow level parameters (DMI, milk yield, genotype, bodyweight etc.) that could affect the individual cow response to a particular supplement, and discusses the current limitations and future challenges for implementing this technology in pasture-based farming systems. Recommendations for future research are made to address any knowledge gaps.

## THE POTENTIAL FOR INDIVIDUALISED FEEDING OF CONCENTRATE SUPPLEMENTS

Any advantage to be gained from the individualised feeding of concentrate supplements to cows, compared with flat-rate feeding, depends on both the existence of sufficient between animal variability, in response to supplementation, and the economics associated with exploiting this variability. Individual differences, in response to supplementation, would imply variation in efficiency of use of the supplement.

(Andre *et al.* 2010) in an observational study of 4 farms in the Netherlands reported considerable between cow variation in milk yields in response to concentrate intake. The researchers concluded this variation could be exploited to improve economic profitability of dairy farming, through optimisation of individual concentrate feeding. By applying individual economic settings for concentrate supply, based on daily milk yield, they were able to show that at least in the short term, potential economic gains ranged from €0.2 to 2.3 /cow per day (Andre *et al.* 2010). There was no consideration of the effect of substitution of forage (either summer grazed pasture and or silage) and the cost of the forage component of the diet in this study and the majority of cows were housed indoors for part or all of the year. In pasture-based systems, the amount of pasture consumed and its nutritive value may influence the between cow variability in response to the supplement (Clark 2013) and will need to be considered as part of a dynamic model for calculating optimum supplementation rates.

## CURRENT LIMITATIONS FOR INDIVIDUALISED SUPPLEMENTATION STRATEGIES

In any production system there is large variability in DMI between animals, although the source of this variability is not well understood. The variation is at its largest and least predictable for grazing ruminants (Allison 1985). (Garcia and Holmes 2005) showed a coefficient of variation of >30-35% in DMI even after correcting for bodyweight amongst cows of similar stage of lactation and having equal access to the same diet (pasture + maize silage). This variability is likely to be driven by a combination of both system (pasture allowance) and cow level factors (e.g. genotype, parity, days in milk, bodyweight etc.)

The lack of information on individual intake and nutritional composition of the pasture component of the diet and the extent to which the addition of a concentrate supplement to the diet affects the amount

of pasture consumed is a significant limitation in formulating individual animal supplementary programs. When supplements are offered to grazing dairy cows they reduce pasture intake with the average milk response to the supplement decreasing as the rate of substitution of supplementary feed for pasture increases (Stockdale 2000, Bargo *et al.* 2003).

Pasture allowance is the system-level factor considered to have the greatest influence on pasture DMI and substitution rate (Stockdale, 2000). Pasture DMI increases with increasing allowance, but at a declining rate (see review by Baudracco *et al.* 2010) leading to a lower proportion of pasture available being harvested and inefficient utilisation of pasture at a level of allowance where maximum DMI is achieved. As a result, in typical rotational grazing systems, it is recommended that pasture allowance be restricted to 90% of the level of pasture availability that would be required to achieve maximum cow's voluntary intake at pasture (Peyraud and Delagarde, 2011). When pasture allowance is restricted, substitution of supplements for pasture is reduced and total DMI and the marginal milk response increase (Grainger and Mathews 1989, Wales *et al.* 1999, Stockdale 2000).

Because pasture allowance has a significant effect on DMI and the substitution of supplements for pasture, which in turn affects the marginal production response to supplements, it is important to understand the extent to which pasture allowance varies and the potential implications of this variability for the individual animal in the herd. From the angle of individual animals rotationally grazed in a dairy farm, pasture allowance (and therefore pasture DMI) can vary due to factors associated with inter (between paddocks), intra (within paddock) and inter-strata (vertical) variability in pasture quantity and quality; and due to factors more specifically associated with the individual animal.

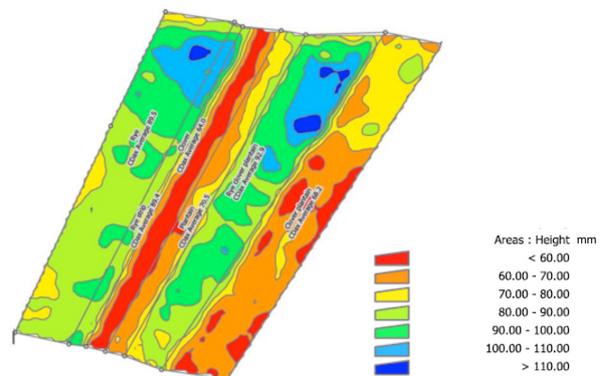
#### *Inter and intra paddock variability in pasture utilisation and yield*

The existence of large intra and inter-paddock variability in pasture yield indicates there is room for improvement in increasing yield by addressing variability, but more importantly in the context of individualised feeding of concentrates, such intra and inter-paddock variability highlights the complexity and variability in terms of the quantity and quality of pasture on offer every time cows are introduced to a new pasture break. The variability in pasture allowances makes it extremely difficult to accurately estimate pasture intake at the individual cow level.

Pasture utilisation (the annual amount of pasture harvested per ha) is a key driver of profitability in pasture-based dairy systems (Garcia *et al.* 2013), but pasture utilisation, is often below demonstrated

potential (DIFMP, 2012). In a recent review, (Garcia *et al.* 2014) demonstrated that the gap between potential pasture utilisation and that achieved in practice can be reduced by improved management of both inputs and grazing. However, even when inputs and grazing management is similar between paddocks (and according to best practice), inter-paddock variability in pasture utilisation remains high. (Garcia *et al.* 2013) combined experimental data from whole farm systems studies from both New Zealand and Australia; in all cases inputs and grazing followed strict management rules. When individual paddock pasture utilisation was expressed relative to the average of each particular study, the results indicated a 100% difference in pasture utilisation between the lowest and highest performing paddocks. Given that this was done with research data, inter-paddock variability is expected to be much higher on commercial farms. (Clark *et al.* 2010) found annualised pasture yields, for individual paddocks across farms, ranged from 9500 to 26100 kg DM/ha/year. Within farms, paddocks with the greatest herbage yield produced between 30 and 122% more pasture DM/ha than the least producing paddocks. There was a poor correlation ( $R^2$  of 0.1 or less) between average paddock yield and yield in the last calendar year for all farms. These data highlight the variability of paddock yield, both spatially within farms and across years (Clark *et al.* 2010).

In addition to inter-paddock variability, there is also large intra-paddock variability (Laca, 2009). There is a lack of specific information about this variability for dairy pastures, however, Pembleton (unpub. data) identified within paddock variability in pasture height, measured using a C-Dax pasture meter, ranging from approximately 70 mm to more than 110 mm in a perennial ryegrass pasture treatment (Figure 1).



**Figure 1:** Variability in pasture height for various pasture swards on a pasture trial plot at the Tasmanian Institute of Agriculture Dairy Research Facility in North West Tasmania. Pasture height was measured using a C-Dax pasture meter (Pembleton, unpub. data).

### *Variability in nutrient content within the pasture strata*

In addition to inter and intra-paddock variability, there is also variability associated with pasture strata. The quality of the diet consumed typically decreases as grazing progresses due to less green leaf and more dead material in the lower stratum (Chacon and Stobbs, 1976). In general, the top stratum of pasture contains less fibre and more crude protein (CP) than the bottom stratum and vice versa, with levels of protein and fibre in an annual ryegrass pasture ranging from 133g/kgDM CP and 675 g/kgDM neutral detergent fibre (NDF) in the bottom 5 cm fraction, to 239 g/kgDM CP and 421 g/kgDM NDF above 15cm (Delagarde *et al.* 2000).

In many pasture-based dairy systems cows arrive back at the pasture after milking over a period of 2-3 hours, and considering cows typically graze pastures in layers (Wade and Carvalho, 2000), cows that arrive last will be presented with both a reduced allowance and lower quality pasture than cows arriving first in the paddock (Scott *et al.* 2014). In the trial reported by (Scott *et al.* 2014), cows that arrived first to a paddock of kikuyu pasture would have had available a diet with approximately 21% greater CP and 15% lower acid detergent fibre than those arriving last.

In conventional dairy systems it is typical for the order of milking, for individual cows, to be consistent between days (Botheras, 2006) with this effect partially being a result of the social dominance herd structure, with the least dominant cows usually located at the rear of the herd (Arave and Albright, 1981). If this is the case, it may be that the more submissive cows are consistently faced with reduced pasture allowances, impacting negatively on their milk yields. These submissive cows should have lower substitution rates and increased responses to supplement and therefore should benefit more from increased levels of concentrate supplementation than would the average cow in a herd. Together with amount of supplement, varying the nutritive value of the supplement in the bail according to milking order, and/or investigating areas of management to decrease the variability in pasture nutritive value accessed within a herd is an area for future research.

In summary, significant inter and intra-paddock variability in pasture yields and utilisation, in addition to large variations in individual intake of pasture, are major limiting factors to the development of individualised supplementary feeding programs for pasture-based dairy cows. Although it is clear that obtaining a direct measure of pasture DMI or substitution is not currently possible at an individual

animal level, there may be opportunities to obtain, via other means, a measure of an individual cow's response to supplements at pasture and use these measures to identify cows with low substitution rates and high responses to supplementary feeds and individually feed these cows for greater efficiency.

## **COW FACTORS**

### *Pasture intake and substitution rate*

In a comprehensive review of factors affecting substitution rate, Stockdale (2000) concluded that pasture intake in unsupplemented cows (i.e. pasture allowance) and bodyweight were the most important factors, although both of these factors explained only 51% of the variation observed. Substitution rate tends to decline with increasing bodyweight (Grainger and Mathews, 1989), although there are effects of cow genetics on substitution rate that are not accounted for by bodyweight (Fulkerson *et al.* 2008). In a study by (Linnane *et al.* 2004) substitution was greater in New Zealand Holstein Friesian cows compared with North American high durability and North American high production Holstein Friesian cows, confirming an effect of genetics on substitution rate.

Grazing behaviour has been shown to be affected by supplementation. Time spent grazing is reduced on average by 12 minutes for every kg of concentrate consumed (Bargo *et al.* 2003, Sheahan *et al.* 2011). However, this effect of time spent grazing is not uniform throughout the day, with a decrease in grazing time associated with supplementation during the morning, but little change in grazing time observed in the evening (Sheahan *et al.* 2011). The use of activity meters warrants further investigation, as a combination of different measures of activities such as grazing time, bite rates and rumination time may be able in the future to be used as proxies for pasture intake and substitution rate for individual cows in the herd.

At the individual animal level, substitution rate is just the consequence of different amounts of pasture and concentrate eaten, which are in turn and to a large extent, regulated by complex physiological mechanisms involved in regulation of voluntary intake. Physical distention of the rumen and gastrointestinal tract, metabolism of products of digestion and endocrine products of the gastrointestinal tract, pancreas and possibly other tissues, all contribute signals that are processed centrally in the brain to control hunger, satiety and energy expenditure (refer to Roche *et al.* 2008 for an extensive review on intake regulation in ruminant farm animals). While physical extension may regulate intake in tropical pastures (Stockdale, 2000),

it does not appear to be a factor in cows grazing high quality digestible temperate pastures (Sheahan *et al.* 2011). Similarly, although hepatic oxidation of energy is involved in satiety in monogastric animals (Allen *et al.* 2009), there is little evidence to support a significant role for intake regulation in grazing dairy cows (Sheahan *et al.* 2013a). There is increasing evidence that neuroendocrine factors involved in intake regulation such as ghrelin may be the component that regulates substitution rate and could potentially be used to identify cows that would produce more milk in response to concentrate supplementation (Sheahan *et al.* 2013, Sheahan *et al.* 2013). Supplementation with concentrates leads to a decrease in ghrelin levels with evidence for supplement type having an effect on substitution rate; starch based concentrates resulted in greater ghrelin decline and increased substitution rate compared with fermentable fibre-based concentrates (Sheahan *et al.* 2013).

In summary, dry matter intake of pasture continues to be the limiting factor in milk production in grazing animals and the significant amount of between cow variability in pasture intake, substitution rate and response to supplements highlights the importance of gaining a better understanding of the factors that explain this variability. Recent attempts to improve the accuracy of estimates of intake at pasture through modelling of both animal and pasture related factors (eg milk yield at peak, pasture allowance, BW etc) are promising (O'Neill *et al.* 2013).

#### *Milk production*

(Bargo *et al.* 2003) in his review on supplementation of grazing dairy cows concluded that on average supplementation increases milk yield, milk protein percentage and yield and milk fat yield, but reduces milk fat percentage. There was considerable variation around this reported response to supplement with much of this variation probably associated with grazing management (discussed above), cow genetics and the type of concentrate offered. In a trial comparing the effect of concentrate supplementation on grass intake and milk production between medium and high genetic merit Holstein-Friesian cows, genotype had a significant effect on all milk production parameters, with the high genetic merit cows having the highest yield of milk, fat, protein and lactose and the medium merit cows having highest milk fat, protein and lactose concentrations (Kennedy *et al.* 2003). (Fulkerson *et al.* 2008) found that cows produced differences in their milk production predicted by their estimated breeding values when grazing cows were fed supplements of greater than 0.8t DM/cow per lactation, but not when

cows were fed low levels of concentrate supplement. These results indicate that the genetic merit of the cows needs to be considered in the decision on the most effective use of supplements.

#### *Energy Balance and Body Condition score*

Body condition score is a subjective assessment of a cow's adipose and muscle tissue stores (Roche *et al.* 2004). A cow's BCS at calving and during the reproductive period, as well as the change in BCS between calving and breeding are important parameters for milk production, health and welfare and reproductive function (refer to a comprehensive review by Roche *et al.* 2009). The two metabolic processes that are associated with changes in BCS are lipolysis and lipogenesis. Simply, when the requirement for energy is greater than the supply of energy, the rate of lipolysis exceeds that of lipogenesis, the cow loses BCS (i.e. is in negative energy balance) and when the supply of energy exceeds requirements the rate of lipogenesis exceeds that of lipolysis and the cow, who is in positive energy balance, stores the excess energy and BCS increases (Brockman and Laarveld 1986, Roche *et al.* 2009). Although BCS loss is a natural mammalian adaptation, intensive selection for milk production has resulted in cows that are prepared to mobilise BCS to the detriment of health and reproduction (Roche *et al.* 2009). After approximately 30 days in milk, the balance between lipolysis and lipogenesis can, on average, be turned in favour of BCS gain in grazing dairy cows by increasing the consumption of concentrate supplements. However, high genetic merit cows require a greater level of concentrate supplement to affect a change in these metabolic pathways (Roche *et al.* 2006). In addition, considering the net efficiency of producing milk from BCS in grazing cows is low because of the low efficiency of BCS gain from autumn pasture (Mandok *et al.* 2013) and the efficiency of gaining condition is 10% greater in lactating cows than dry cows (Moe and Tyrrell 1972, Yan *et al.* 1997), the opportunity to manage BCS through individualised feeding should improve feed conversion efficiency on grazing dairy farms.

In summary, the collective literature indicates a significant 'cow effect' in the marginal milk production response to supplements. It is plausible that some combination of these cow factors and cow x grazing management interacting factors could be used to define appropriate supplementation of cows such that the final milk production response to supplementary feeds (i.e. immediate and deferred responses) will be greater than if all cows in the herd were fed similarly (i.e. flat-rate feeding).

## IMPLICATIONS FOR REPRODUCTION HEALTH AND WELFARE

Apart from the objective of optimising milk or milk solids through increased milk response to supplement, the reproductive success and health and wellbeing of cows needs to be considered.

### *Rumen function and health*

Providing concentrate supplements to dairy cows will have an effect on rumen function. As already discussed, in pasture-based systems there is no practical measure of the amount and nutritive value of pasture being consumed and even if measurement was possible, it is unlikely, that the balance of non-structural carbohydrate (NSC) to NDF and other factors is the same for all cows in the herd. This indicates that individualised management of cows will require the identification of an, as yet, unknown factor that reflects when rumen parameters are indicative of poor rumen function.

Recent evidence indicates there is a threshold level of NSC consumption, below which, the cow functions normally, but above which, she functions sub optimally (Auld *et al.* 2014). If this threshold can be identified, the diet can be adjusted to replace NSC with fermentable fibre sources, or include rumen modifiers, that reduce the risk of acidosis and increase DMI, feed conversion efficiency and milk production. The large variability between animals in response to rumen modifiers (Golder *et al.* 2014) supports the need for a biomarker that is indicative of poor rumen health, to ensure all animals are managed optimally.

### *Heat stress*

Heat stress leads to a reduction in DMI and milk production, but there is considerable variation in heat tolerance between breeds and between individuals within a breed (Hansen 2004, Gaughan *et al.* 2009). Where heat stress can be identified as a risk factor, diets could be adjusted to reduce the heat of fermentation (e.g. through increasing the energy density and increasing the amount of bypass starch or perhaps by including additives such as chromium (Dunshea *et al.* 2013)). Being able to identify those animals at increased risk of heat stress and individually feed them suitable mixtures of supplements is integral to the success of individualised feeding strategies that reduce negative effects of heat stress on production and welfare of lactating dairy cows.

### *Reproduction*

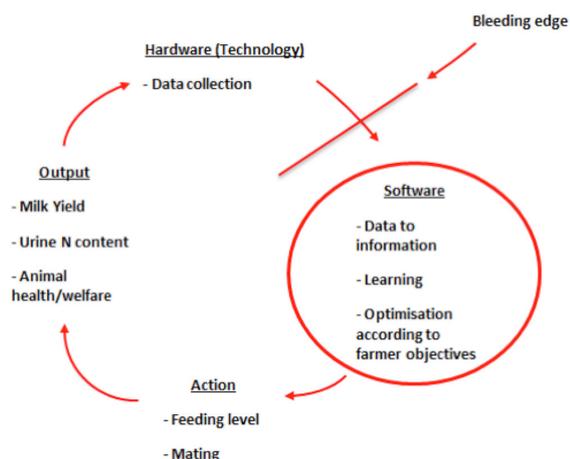
Diet composition has a putative role in dairy cow reproductive success, but dietary adjustment to improve pregnancy rates is complicated, and merely offering pasture-based cows a supplement is unlikely

to result in large effects (Refer to the comprehensive review by Roche *et al.* 2011). There is evidence for an anoestrus-reducing effect arising from altering the NSC to structural carbohydrate ratio in early lactation (Gong *et al.* 2002, Garnsworthy *et al.* 2008). However, supplementation with NSC in pasture-based systems does not appear to elicit this effect. In addition, a high NSC to structural carbohydrate ratio reportedly results in reduced pregnancy rates (O'Callaghan and Boland 1999). Further research is required to better understand the effect of carbohydrate type on pre- and postovulatory reproductive function, as, if influential, there is a potential role for individualised feeding of different feed ingredients to dairy cows at different days in milk and/or relative to stage of reproduction.

The effect of CP, soluble CP, and rumen degradable protein in reproductive function is not clear. From a reproductive standpoint, pasture-based evidence does not support a role for altering protein amount or composition, but there is a lack of large scale interventionist studies to confirm this. This is an area for future research in grazing systems. Similarly to CP, the effect of dietary fat and fatty acid composition upon reproductive performance is not clear, but there may be an advantage to the addition of specific fatty acid to the ration (Ambrose *et al.* 2006). Further research is required to determine the role of fatty acid on pre- and post-ovulatory reproductive function.

## FUTURE CHALLENGES AND OPPORTUNITIES

As advances in technology have made it easier to collect and store data, identifying what data might be useful and how such data could be interpreted to enable appropriate decisions to be made is becoming increasingly difficult. Much of this data is collected using differing technology and devices limiting the ability to consolidate the data on a single platform for assessment, often meaning that data collected is not effectively utilised as an aid to decision making by farmers. This increasing integration of technology on farm, with an inability to meaningfully use the technology, can be termed 'the bleeding edge' (Figure 2), where money and time has been 'bled' for no outcome. The successful integration of technology on-farm will require development of software to integrate and package data into something meaningful that allows efficient decisions to be made by farmers i.e. taking them from 'the bleeding edge' to the leading edge.



**Figure 2:** The increasing integration of technology on farm, with an inability to meaningfully use the technology, can be termed ‘the bleeding edge’, where money and time has been ‘bled’ for no outcome.

In the future, farmers, via intelligent decision support systems, could be allocating differing supplements to individual cows, based on algorithms that include details about the feed (pasture type, grain type), animal (genetic merit, bodyweight, condition score, specific biomarkers, reproductive status, days in milk) and environmental parameters (heat or cold stress) rather than just basing decisions on one or two parameters, such as milk yield and/or bodyweight, as is currently the case for many farms with computerised bail feeding and milk meters.

The question still remains as to how to adequately collect and combine appropriate data from various sources. Currently the data that is readily available for use in intelligent support systems include measures such as daily milk yield, daily bodyweight, grazing and rumination activity and milking order. These sources of data, along with external data, such as temperature and economic factors including feed and milk price could all be used in the development of a dynamic model for the allocation of supplements. One method to address the uncertainty regarding the appropriateness of parameters to enable efficient allocation of supplements is to learn everything we can about cow responses from multiple component trials. In practice this is not possible. Another method would be to utilise current technology and data generated from existing systems to do this ‘learning’ for us. Given the numerous individualised feeding strategies on offer, research has a role to pull the results obtained from current feeding strategies together into an overarching model to aid on-farm supplementary feeding decisions.

Recent research (Romera *et al.* 2010) has highlighted the ability to fit empirical parameters to

observations to ‘train’ a model resulting in increased accuracy of individual paddock pasture growth predictions. In effect, this model (PGSUS) ‘learns’ from the past to better predict the future. A similar approach has been proposed, and tested, using daily milk recordings and milking interval durations in an automatic milking system to estimate the individual dynamic milk yield response to concentrate intake (Andre *et al.* 2010). In (Andre *et al.* 2010)’s model, there is no consideration of rumen health, weighting for reproductive considerations and measurement of factors that could account for variations in pasture intake or substitution rates. Other similar approaches include the concept of statistical process control and the synergistic control concept to model real time (online) data for early detection of anomalies (Huybrechts *et al.* 2014).

It is proposed that a similar approach to the models discussed above be developed and tested for pasture-based cows. An example of the way to approaching this would be to enable the system to automatically conduct an “experiment” with the entire herd, to estimate feed/supplement responses. This machine learning process effectively removes the need for a manager to examine data from various sources for each cow and then make decisions on how best to use the available information to feed supplements. Over time, the accuracy of the machine learning model will improve, and with improvement increase the potential for efficient use of supplements in pasture-based dairy systems.

## CONCLUSION

While there is currently little evidence to support the premise of improved production from the individualised feeding of concentrate supplements to pasture-based dairy cows, the existence of significant variation in pasture and total DMI of herd-managed cows and in milk response to supplements suggests that efficiency gains from appropriate individualised feeding programs should lead to improved marginal milk responses. Significant variability in the quantity and quality of pasture available to individual cows, currently limits the ability to determine both pasture intake and substitution rates for individual cows. This variability may be part of the reason milk response to concentrate supplements in individualised feeding programs has not led, in most cases, to improved milk production. A number of cow factors that have been identified could provide a means for determining cows within a herd that have low substitution rates and high response to supplements. Further research needs to be conducted to better understand the relationship between factors, such as, grazing and other activity based behaviours and pasture intake and substitution

rates. Intrinsic factors related to metabolism and the physiology of intake regulation appear to be most promising. In particular the potential to use satiety hormones such as ghrelin for identifying animals with lower substitution and increased supplement also requires further research. The inclusion of these parameters, along with routinely collected data such as milk yields and bodyweight, could be used in the development of a 'self-learning' model that estimates an individual cow's response to supplement and improve allocation of concentrates across the whole herd. This type of model will need to consider the impact of changing levels of concentrates on rumen function, health, welfare and reproduction. The development of 'self-learning' models for individualised feeding of concentrates should be a focus for future research.

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