

Comparing the use of dry matter intake and residual feed intake to improve feed efficiency in Holstein cattle

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Abstract

The inclusion of feed efficiency into breeding objectives for dairy cattle has been a topic of discussion for many years. As feed costs rise and the environmental impacts of agriculture are increasingly scrutinized, improving the efficiency at which dairy cows convert feed to milk is becoming more important. There are many ways to define feed efficiency, with much discussion surrounding optimal traits and strategies. The objective of this research was to compare the effects of holding dry matter intake constant while selecting to increase production versus selecting on residual feed intake, both of which can be considered potential mechanisms for improving feed efficiency in dairy cattle.

A subset of traits genetically evaluated in Canada were chosen to represent various aspects of the current breeding program. These traits included first parity measures for: 305-day fat yield, 305-day protein yield, body condition score, stature, age at first service (heifer), days from first service to conception, clinical ketosis, and displaced abomasum. Different breeding goals were considered using a deterministic modeling program. The inclusion of either dry matter intake or residual feed intake in the index was analyzed considering two methods. One scenario of the current breeding goal, where no selection pressure was applied on either dry matter intake or residual feed intake, and selection based on the indirect response was evaluated. The other method applied selection pressure to either hold dry matter intake constant or reduce residual feed intake, and the direct response to selection was evaluated. Annual genetic gain and monetary genetic gain were assessed for both scenarios.

When no selection pressure was applied, both traits had an unfavourable response to selection, whereas with direct selection pressure, the response was favourable for both traits. Selecting to hold dry matter intake constant while selecting to increase production had a similar response to selection for improving feed efficiency compared to selecting on residual feed intake. This could indicate that both dry matter intake and residual feed intake would be effective at improving the efficiency at which cows utilize their feed for milk production.

Key words: dairy cattle, feed efficiency, selection index

Introduction

Improving farm efficiency is a priority for industry leaders, producers, environmentalists, and consumers. Feed utilization accounts for a large inefficiency in the dairy system, along with a large expense for the producer. It is estimated that feed accounts for close to 50% of production related costs, and this cost is expected to rise in the coming years (Beever et al., 2007; Hemme et al., 2014; Connor, 2015).

With the global population expected to reach 8.5 billion people by the year 2030, land needed to grow food for human consumption will become more valuable (United Nations, 2015). Along with an increase in population size, the average wealth of the middle class is expected to rise, leading to a demand for high quality, sustainably produced products (Government of Canada, 2018). Targeting the inefficiency in feed utilization is a potential way to improve on-

farm efficiency, while reducing producer expenses.

The selection for more efficient animals has been successful in other species. The swine, beef, and poultry industries have all successfully selected for more efficient production of meat and egg products, respectively (Patience et al., 2015; Gadde et al., 2017; Kenny et al., 2018). In dairy cattle, it has been shown that animals with high genetic potential for production tend to consume more food to meet their high production requirements (Kenny et al., 2018). Variation in the amount of feed consumed between animals of similar production levels, however, has been observed, suggesting the ability to select for animals that are more efficient at converting feed to milk (Veerkamp et al., 1995; Herd and Bishop, 2000). Improving feed efficiency therefore has the potential to decrease feed costs without decreasing production (Pryce et al., 2015). The objective of this research was to compare the effects of holding dry matter intake constant while selecting to increase production versus selecting on residual feed intake, both of which can be considered potential mechanisms for improving feed efficiency in dairy cattle.

Materials and Methods

Trait Definitions

Ten traits were selected to be used in this research, where eight are routinely genetically evaluated in Canada, and two are novel. The currently evaluated traits were from first lactation animals only and included two production traits - fat yield (**FY**) and protein yield (**PY**), two type traits - stature (**STAT**) and body condition score (**BCS**), two fertility traits - age at first service (**AFS**) and interval from first service to conception (**FSTC**), and two health traits - clinical ketosis (**CK**) and displaced abomasum (**DA**). The novel traits selected for inclusion were dry matter intake in early lactation (**DMI**) or residual feed intake (**RFI**), both related to feed efficiency. The DMI was defined as the average amount of daily dry matter consumed in kilograms by an animal for their first 60 days in milk during their first lactation. Residual feed intake was the residual part of the regression of DMI on fat and protein corrected milk yield, and metabolic body weight. Trait definitions, heritability, genetic

standard deviation and genomic accuracy is presented in Table 1.

Population Structure

Modelling of breeding programs which included either DMI or RFI was performed using a deterministic modeling program, ZPLAN+, which allows for modeling of genetic and economic parameters within complex breeding programs (Täubert et al., 2010). The population structure for this modeling program contained both male and female selection pathways. The male selection pathway comprised three selection steps. To begin there were 30 000 genotyped bull calves (< 1 year of age), where 7% were selected to become genomic bulls and enter the AI market, following Van Doormaal (2014). After three years 5% of the genomic bulls, who had at least 100 daughter records, were selected to become proven bulls as per Van Doormaal (2014). There were two selection steps in the female selection pathway. Beginning with 500 000 heifer calves, 10% were selected to become elite females which were used to produce the next generation of bulls as per Schaeffer (2006). From the same initial 500 000 heifers, 85% joined the milking herd at the time of first calving as in Schaeffer (2006). Elite females were mated exclusively to genomic bulls, while 70% of the general milking herd were mated to genomic bulls and 30% mated to proven bulls following Van Doormaal (2017).

Economic Values

The assumed breeding objective was to improve fat and protein yield, while simultaneously improving health and fertility. The economic values for conformation traits were optimized therefore the traits would be held constant in all scenarios. The optimal economic value to hold both traits constant was calculated using the multiple trait desired gains excel program (Van der Werf, 2015). Literature economic values were obtained for fertility and health traits, and were \$2.57 per day for AFS (Lang, 2016), \$3.36 per day for FSTC (De Vries et al., 2004), \$233.00 per case of CK (Gohary et al., 2016), and \$707.00 per case of DA (McArt et al., 2015). Economic values were calculated for production traits using the profit equation, where revenue was the average producer paid price for the trait from May 2018 to April 2019 (\$10.85 per kg, FY, and \$7.64 per kg, PY) and

the cost assumed was the amount of dry matter needed to produce one kilogram of the desired trait. All values presented are in Canadian dollars. The cost of 1.00 kg of dry matter was assumed to be \$0.29 and the amount of dry matter needed to produce 1.00 kg of fat and protein was assumed to be 6.00 kg and 3.70 kg, respectively (Richardson et al., 2019). The calculated economic values for FY and PY were \$9.11 and \$6.57, respectively. The economic value for RFI was assumed to be \$-88.45, which was the cost of improving feed efficiency by 1.00 kg of dry matter per day over a 305-d lactation. This economic value assumed a cost of 1.00 kg of dry matter to be \$0.29 and the cost of dry matter was then multiplied by 305 to achieve the economic value to improving feed efficiency by 1.00 kg of dry matter per day over a 305-d lactation. The optimal economic value to hold DMI constant was calculated using a multiple trait desired gains excel program (Van der Werf, 2015).

Selection Scenarios

Four selection scenarios were considered to assess the impacts of including DMI or RFI in a selection index to improve feed efficiency. To represent current selection methods, DMI and RFI were included separately with no index weight, allowing for the assessment of the correlated response to selection. These scenarios were named using the extension NS to denote no selection (**DMI_NS** and **RFI_NS**). The incorporation of DMI into the index was carried out by holding the trait constant in the index while selecting to increase production. Incorporating RFI was done by applying negative selection pressure to improve feed efficiency. Both indexes where selection pressure was applied were named with the extension SP to denote selection pressure (**DMI_SP** and **RFI_SP**). All selection indexes were economic indexes, meaning the trait index weight was based on the traits' variances and covariances and economic value.

Results and Discussion

The trait response to selection was assessed by comparing the response estimated for the DMI and RFI scenarios to the trait response in the DMI_NS and RFI_NS, respectively. When comparing the response of FY and PY in DMI_SP to DMI_NS, FY had a slightly lower

response to selection of 0.01 genetic standard deviation (**SD**) units per year and PY had a slightly higher response to selection of 0.01 SD units. Comparing RFI_SP to RFI_NS, both FY and PY had a slightly lower response to selection at 0.01 SD units. Since the breeding goal for BCS and STAT was to remain constant, no difference in response to selection was observed between the scenarios. The fertility traits were the most impacted by the inclusion of feed efficiency traits. When using DMI as a feed efficiency trait, AFS had a response to selection of 0.13 SD units longer, while FSTC had a response to selection of 0.09 SD units longer compared to the DMI_NS. The inclusion of RFI had less of an impact on fertility traits where AFS was less than 0.01 SD units longer and FSTC was 0.01 SD units longer. The disease traits in all indexes had a very low response to selection, in all cases less than 0.01 SD unit change in incidence of disease. This remained constant when including feed efficiency. While the impact was greatest for the fertility traits, the difference in response between the scenarios was less than 0.2 SD units which is still a small change. Trait response to selection is presented in Table 2.

In order to further understand how including feed efficiency in a selection would impact the other traits, the proportion of the overall response to selection attributed to each trait was investigated. In both DMI_NS and RFI_NS, FY and PY made up over 60% of the response to selection. This was not surprising as these two traits were the most economically important in the index, being the traits that producers get paid for. This proportion of the overall response to selection for the production traits remained consistent in DMI_SP and RFI_SP. The fertility traits made up about 20% and 7% of the overall response to selection for AFS and FSTC, respectively. The proportion changed slightly in DMI_SP, where there was a reduction in the proportion of the overall response to selection for AFS to 14%, and an increase for FSTC to 10%. The proportion for AFS and FSTC remained constant for RFI_SP compared to RFI_NS. All other traits, BCS, STAT, CK and DA, had less than 5% of the overall response to selection in all scenarios. In all cases the proportion of the overall response to selection attributed to the feed efficiency traits was less than 2%, with the highest being DMI in the DMI_NS scenario at 1.75%. The proportion of

the overall response to selection attributed to each trait is presented in Figure 1. In general, there were no large detrimental effects to traits of interest when including feed efficiency into the selection index.

Including either DMI or RFI into a selection index has potential to improve feed efficiency in a similar manner. The difference in yearly response to selection for the no selection (DMI_NS and RFI_NS) and selection (DMI_SP and RFI_SP) scenarios can be considered the genetic potential for the amount of more efficiently used feed. Considering holding DMI constant while selecting to increase milk production, animals would have the genetic potential to use 0.04 SD units of dry matter more efficiently per year, translating into direct savings for producers. These findings were in agreement with previous work by Veerkamp et al. (2014). A similar trend was observed when using RFI to improve feed efficiency, where animals would have the genetic potential to use 0.02 SD units of dry matter more efficiently per year. Compared to DMI_SP, there was a difference of 0.02 SD between the two feed efficiency traits, where DMI_SP was slightly higher. Using RFI as a measure of feed efficiency can have challenges as it is the residual term of a regression of DMI on energy sinks, where varying models can impact the estimation of RFI (Seymour et al. 2019). However, using either DMI or RFI as outlined in this study allows for production to continue to improve while simultaneously improving feed efficiency.

The inclusion of RFI compared to DMI in a selection index for the purpose of improving feed efficiency has been previously investigated by Kennedy et al. (1993) and Lu et al (2015). This study, in agreement with Kennedy et al. (1993) and Lu et al (2015), found that a similar response to selection could be achieved when selecting on the components of RFI as when selecting on RFI directly. Other countries have already incorporated feed efficiency into their selection programs, such as Australia with the inclusion of Feed Saved index (Pryce et al., 2015). Through their selection program, animals that are one SD above the mean of the Feed Saved index consume 65 kg less feed per year, while maintaining the same level of milk production (Pryce et al., 2018). This further

shows that improving feed efficiency while maintaining production levels is possible.

Conclusions

This study compared the effects of improving the feed efficiency of dairy cattle through two selection methods. When holding DMI constant in the selection index, no detrimental effects were observed to the other traits in the index, and 0.04 SD units per year of DMI was used more efficiently. Similar to selecting on DMI, when including RFI into an index, no detrimental effects were observed on the other traits within the index. Applying a negative selection pressure to RFI led to an improvement of 0.02 SD units per year for RFI. The response to selection observed in both DMI and RFI suggest that these traits should be considered in selection programs with the goal of improving feed efficiency.

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Table 1. Trait definitions, genetic and phenotypic standard deviations, heritability estimates and genomic accuracy

| Abbreviation | Definition | Genetic standard deviation | Heritability (standard deviation) | Genomic accuracy |
|--------------|---|----------------------------|-----------------------------------|-------------------|
| FY | Fat yield during a 305-day lactation | 18.11 | 0.32 (0.06) | 0.80 ¹ |
| PY | Protein yield during a 305-day lactation | 12.87 | 0.27 (0.04) | 0.79 ¹ |
| BCS | Measure of the fat covering over the tail head and rump on a scale of 1 (very thin) to 5 (very fat) | 0.14 | 0.24 (0.07) | 0.77 ¹ |
| STAT | Measure from the top of the spine in between hips to ground | 1.82 | 0.46 (0.01) | 0.77 ¹ |
| AFS | Number of days from birth to first insemination of the animal | 5.50 | 0.05 (0.02) | 0.69 ¹ |
| FSTC | Number of days from first service to conception in first lactation | 7.20 | 0.03 (0.00) | 0.74 ¹ |
| CK | Binary scored trait (0-no case/unknown, 1-at least one case of clinical ketosis) in first lactation | 0.84 | 0.04 (0.02) | 0.61 ¹ |
| DA | Binary scored trait (0-no case/unknown, 1-at least one case of displaced abomasum) in first lactation | 0.84 | 0.02 (0.01) | 0.59 ¹ |
| DMI | Average daily dry matter intake in the first 60 days in milk | 165.05 | 0.49 (0.01) | 0.59 ² |
| RFI | Average daily residual feed intake in the first 60 days in milk | 93.45 | 0.28 (0.07) | 0.40 ³ |

¹Canadian Dairy Network, 2017

²Miglior et al., 2018

³Pryce et al., 2014

FY = fat yield (kg), PY = protein yield (kg), BCS = body condition score (score), STAT = stature (cm), AFS = age at first service (days), FSTC = first service to conception, CK = clinical ketosis (case),

DA = displaced abomasum (case), DMI = dry matter intake (kg/day), RFI = residual feed intake (kg/day)

Table 2. Genetic gain per year standardized by the genetic standard deviation

| Scenario | FY | PY | BCS | STAT | AFS | FSTC | CK | DA | DMI | RFI |
|----------|-------|-------|--------|-------|--------|-------|-------|-------|-------|--------|
| DMI_NS | 0.813 | 0.739 | 0.008 | 0.047 | -0.450 | 0.135 | 0.001 | 0.002 | 0.039 | - |
| DMI_SP | 0.802 | 0.753 | -0.095 | 0.046 | -0.322 | 0.228 | 0.001 | 0.003 | 0.001 | - |
| RFI_NS | 0.816 | 0.741 | -0.023 | 0.034 | -0.446 | 0.177 | 0.002 | 0.002 | - | 0.014 |
| RFI_SP | 0.808 | 0.728 | -0.009 | 0.038 | -0.447 | 0.184 | 0.004 | 0.002 | - | -0.005 |

FY = fat yield (kg), PY = protein yield (kg), BCS = body condition score (score), STAT = stature (cm),
 AFS = age at first service (days), FSTC = first service to conception (days), CK = clinical ketosis (case),
 DA = displaced abomasum (case), DMI = dry matter intake (kg/day), RFI = residual feed intake (kg/day)
 NS = no selection, SP = selection pressure

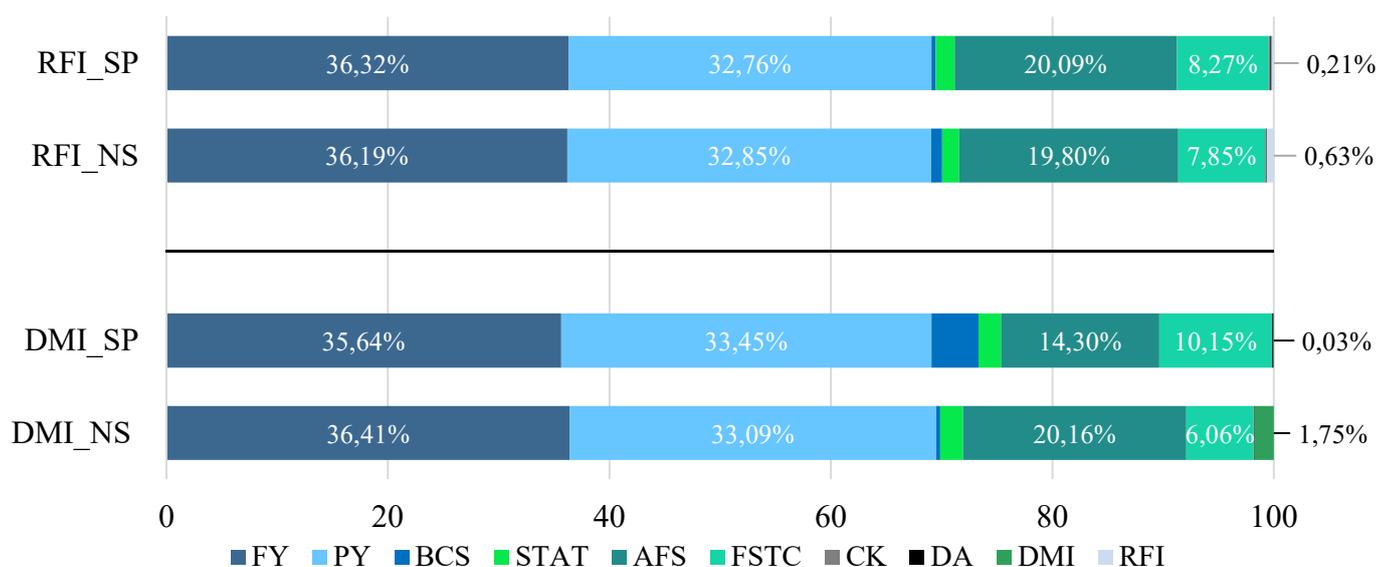


Figure 1. The proportion of overall response to selection attributed to each trait when dry matter intake (DMI) or residual feed intake (RFI) was included in the scenario. Unlabeled bars are traits with less than 5% of the total overall response to selection. The proportion of the overall response to selection attributed to DMI and RFI are to the right of the figure.

FY = fat yield (kg), PY = protein yield (kg), BCS = body condition score (score), STAT = stature (cm),
 AFS = age at first service (days), FSTC = first service to conception (days), CK = clinical ketosis (case),
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