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Development of a Lifetime Merit-based selection index for US dairy grazing systems

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ABSTRACT

Pasture-based dairy producers in the United States face costs, revenue streams, and management challenges that may differ from those associated with confinement dairy production systems. Three Grazing Merit indices (GM$1, GM$2, and GM$3), parallel to the US Lifetime Net Merit (NM$) index, were constructed using economic values appropriate for grazing production in the United States. Milk prices based on averages from the previous 5 yr were used for GM$1, whereas GM$2 and GM$3 used milk prices found in NM$. Cull prices and interest rates from NM$ were used in GM$3 but were updated for GM$1 and GM$2. All other inputs remained constant among GM$1, GM$2, and GM$3. Economic costs and revenues were obtained from surveys, recent literature, and farm financial record summaries. Derived weights for GM$ were then multiplied by the predicted transmitting abilities of 584 active artificial insemination Holstein bulls to compare with NM$. Spearman rank correlations for NM$ were 0.93 with GM$1, 0.98 with GM$2, and 0.98 with GM$3. Traits (and their percentages of weight) comprising GM$1, GM$2, and GM$3, respectively, included milk volume (24, 0, 0%), Fat yield (16, 21, 21%), protein yield (4, 17, 17%), productive life (7, 8, 7%), somatic cell count (−8, −9, −9%), feet and legs composite (4, 4, 4%), body size composite (−3, −4, −4%), udder composite (7, 8, 8%), daughter pregnancy rate (18, 20, 20%), calving ability (3, 3, 3%), and dairy form (6, 6, 6%). These weights compared with NM$ weights of 0, 19, 16, 22, 10, 4, 6, 7, 11, 5, and 0% for the same traits, respectively. Dairy form was added to GM$ to offset the decrease in strength associated with selection to reduce stature through selection against body size. Emphasis on productive life decreased in GM$ because grazing cattle are estimated to remain in the herd considerably longer, diminishing the marginal value of productive life. Although NM$ provides guidance for grazing dairy producers, a GM$ index based upon appropriate costs and revenues allows for selection of cows and bulls for more optimal genetic progress.
Key words: economic value, genetic, grazing, selection index

INTRODUCTION

The increased focus on pasture-based dairy production has prompted several studies in the United States and other countries to determine the effect of genotype by environment interaction (**G×E**) for grazing production compared with confinement dairy production. These studies have involved several economically important traits such as milk production, SCC, conception rate, and milk component percentages. A G×E effect occurs when the environment affects the way genes are expressed, resulting in a change in the phenotype of the animal in one environment versus another (Bourdon, 2000).

Recent studies have pointed out that a modest G×E primarily because of scaling does exist; however, the effect is not sufficient to create an economically feasible impetus for separate progeny tests for confinement and pasture-based production systems (Weigel et al., 1999; Boettcher et al., 2003; Kearney et al., 2004; Coleman et al., 2009). Although G×E is minimal for individual traits, the aggregate value of the animal in each distinct environment may be different. Many grazing dairy producers are convinced that current US genetics do not and cannot meet their needs because the current US indices are based largely on DHIA test data. Many grazing producers do not participate in DHIA tests, for various reasons but commonly to avoid the associated costs. Therefore, grazing data are under-represented in US genetic evaluations of AI bulls and selection indices.

Traditionally, the theory of index selection utilizes phenotypic correlations, heritabilities, and the genetic relationships among desired traits to enhance accuracy and generate a single PTA per animal that represents the aggregate breeding value. However, many produc-

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ers may benefit from the availability of individual trait PTA to achieve selection for their specific breeding goals. Because a single whole-animal PTA is not generated, multiple PTA are calculated that account for heritabilities and correlations. In the selection index approach typically used for US selection indices, only economic weights need be considered, because the supplied PTA include the genetic parameters in their calculation (VanRaden, 2004).

Historically, the US economic indices used only production traits to estimate the economic value of an animal. However, in 1994, the idea of the US Net Merit$ (**NM$**) index was expanded to include fitness traits. This new index added the concepts of economic value of productive life and SCS, as well as the traditional production traits (VanRaden, 2004).

Additional changes were made to the US NM$ in 2000, when the development of a lifetime profit function made inclusion of type traits (conformation composites) possible. Scientists in the USDA regional research project S-284, "Genetic Enhancement of Health and Survival for Dairy Cattle," constructed the function that included traits milk volume (**MY**), fat yield (**FY**), protein yield (**PY**), udder composite (**UC**), SCS, feet and legs composite (**FLC**), body size (**BS**), and productive life (**PL**).

Over time, additional changes have been made to the US NM$, essentially broadening the focus of the index. These updates have moved the index from being purely production oriented to a balanced index with concurrent emphasis on both production and functional traits. In 2003, 2006, and 2010, financial weights were re-evaluated, revised, and updated to maintain relevance in a changing dairy industry. Additional traits were added to the index as evaluations became more readily available. In 2003, NM$ was changed to include daughter pregnancy rate (**DPR**) and service sire (**SCE**) and daughter (**DCE**) calving ease. In 2006, SCE and DCE were combined with service sire stillbirth and daughter stillbirth to create calving ability dollars (**CA$**).

Today, the economic values used in NM$ are the result of several major studies and data from the DHIA. These sources allow NM$ to include accurate estimates of the values to be placed on traits; however, the data are based on records primarily from confinement dairies, due to the low participation rates of grazing dairies in DHI testing and conformation scoring through breed associations. Existing genetic evaluation data may fairly represent breeding objectives for grazing farmers; however, the actual degree to which they are represented has yet to be determined.

The objective of this study was to evaluate the suitability of NM$ for grazing production and determine the suitability of separate grazing merit indices developed by replacing the input values found in the net merit equations with values more relevant to grazing production systems.

MATERIALS AND METHODS

Input Equations

Grazing Merit 1 (**GM$1**), Grazing Merit 2 (**GM$2**), and Grazing Merit 3 (**GM$3**) were derived using a similar approach to that used for the NM$ equations obtained from Animal Improvement Programs Laboratory of the USDA (Cole et al., 2010). Adjustments to appropriate input values were made to more accurately reflect values found in grazing dairy production systems. Basic input values for all indices are in Table 1.

The current NM$ consists of 4 additive parts: Yield $, Udder $, Other $, and CA$, each of which are described below (Cole et al., 2010). In the components of Yield $ are the contributions of MY, PY, and FY, whereas Udder $ includes UC and SCS. The contributions of PL, BS, FLC, and DPR are included in Other $. The CA$ portion of the index is a composite calving ability that includes sire and daughter dystocia and still birth. The original NM$ equations can be found in the Appendix.

Yield $

The equations for MY, FY, and PY are as follows:

$$\text{MY} = (milkval - milkfeed - milkhealth) \times lactns,$$

$$\text{FY} = (fatval - fatfeed - fathealth) \times lactns, \text{ and}$$

$$\text{PY} = (protval - protfeed - prothealth) \times lactns;$$

where *milkval*, *fatval*, and *protval* are the income values of milk volume and fat and protein yields, respectively; *milkfeed*, *fatfeed*, and *protfeed* are the added feed costs for milk, fat, and protein, respectively; *milkhealth*, *fathealth*, and *prothealth* are the added health costs for milk, fat, and protein, respectively, for cows producing the additional milk; and *lactns* is the average number of lactations of a cow.

Input values for MY, FY, and PY under GM$1 were derived using average prices of the National Agriculture Statistics Services (NASS) milk, Cheddar cheese barrel, and butter prices from 2006 to 2011. The values of butterfat (*fatval*) and protein (*protval*) were derived from Cheddar cheese barrel and butter prices using USDA equations. Milk volume price is the residual value after accounting for the value of butterfat and protein. Feed values (*milkfeed*, *fatfeed*, *protfeed*) were determined to be 41% of added income from the NASS milk price/cwt.

Table 1. Input values for Grazing Merit$ 1 (GM$1), Grazing Merit$ 2 (GM$2), Grazing Merit$ 3 (GM$3), and USDA Net Merit$ (NM$)

Input	GM$1	GM$2	GM$3	NM$[1]
Cull price (*cull*; $)	0.5460	0.5460	0.5281	0.5281
Death rate (*death*)	0.1980	0.1980	0.1980	0.2005
Calf value (*calfval*; $)	350.00	350.00	350.00	250.00
Fixed replacement cost (*fixrep*; $)	68.18	68.18	68.18	396.00
Precalving variable replacement cost (*varrep*; $)	0.91	0.91	0.91	1.08
Postcalving replacement cost (*postrep*; $)	0.340	0.340	0.340	0.405
Interest rate (*intrate*; %)	0.050	0.050	0.075	0.075
Maintenance cost (*maint*; $)	0.1760	0.1760	0.1760	0.2025
Somatic cell cost (*scscost*; $)	13.79	13.79	13.79	18.00
Udder value (*uddval*; $)	11.00	11.00	11.00	11.00
Feet and legs value (*flval*; $)	5.00	5.00	5.00	5.00
Daughter pregnancy rate value (*dprval*; $)	13.80	13.80	13.80	8.50
Mean for productive life (*meanPL*; mo)	45.00	45.00	45.00	29.16
Mean for weight (*mean weight*; kg)	589.68	589.68	589.68	680.40
Milk volume value (*milkval*; $/kg)	0.1770	0.0604	0.0604	0.0604
Milk feed cost (*milkfeed*; $/kg)	0.0542	0.0476	0.0476	0.0476
Milk health cost (*milkhealth*; $/kg)	0.0192	0.0119	0.0119	0.0119
Fat value (*fatval*; $/kg)	3.4833	3.5935	3.5935	3.5935
Fat feed cost (*fatfeed*; $/kg)	1.3889	1.1684	1.1684	1.1684
Fat health cost (*fathealth*; $/kg)	0.2425	0.2425	0.2425	0.2425
Protein value (*protval*; $/kg)	2.6014	4.2769	4.2769	4.2769
Protein feed cost (*protfeed*; $/kg)	1.8298	1.5432	1.5432	1.5432
Protein health cost (*prothealth*; $/kg)	0.0882	0.1543	0.1543	0.1543

[1]Source: J. B. Cole (USDA, Beltsville, MD, personal communication).

(Cole et al., 2010). Health values (*milkhealth*, *fathealth*, *prothealth*) were determined to be 8% of the NASS milk price/cwt. (Cole et al., 2010). Feed and health costs were distributed among milk, fat, and protein proportionally. This is the same method used in the NM$ program to calculate feed and health costs. These feed and health cost values were changed from $0.0476 and $0.0119, to $0.0542 and $0.0192 per kg of milk; $1.1684 and $0.2425 to $1.3889 and $0.2425 per kg of fat; and $1.5432 and $0.1543 to $1.8298 and $0.0882 per kg of protein to reflect the change in milk price. Input values for GM$2 and GM$3 remained consistent with those in NM$ to allow a more equivalent comparison. These values parallel those used in NM$, which are based on the average utilization of milk across the country. Because fluid milk consumption is down and consumption of cheese and other products is up, there is decreased weight on MY and an increased weight on PY.

The *lactns* for a cow was derived from the following formula:

$$lactns = meanPL \times 0.1,$$

where *meanPL* is the mean length of productive life for a cow. For the grazing merit indices, *meanPL* was altered from 29 to 45 mo (Table 1) to reflect the greater herd life of cows in grazing systems based on the proceedings of the Western Veterinary Conference (Marshall, 2009). The factor of 0.1 converts months of PL into number of lactations.

Udder $

Udder Composite. The contribution of UC was derived from the following equation:

$$\text{UC} = uddval \times lactns,$$

where *uddval* is the value for udder conformation, which remained consistent with values found in NM$.

SCS. The contribution of SCS was determined as

$$\text{SCS} = scsval \times lactns,$$

where *scsval* reflects the total value of a unit decrease in SCC and was formulated as follows:

$$scsval = scsprem \times meanMY - scscost,$$

where *scsprem* is the monetary premium per pound added for milk having reduced SCC, *meanMY* is the mean milk yield, and *scscost* is the cost associated with a case of mastitis. The *meanMY* was reduced to 85% of the Holstein breed average reflecting the findings of Kearney et al. (2004) regarding the effect of G×E interaction on milk yield in grazing dairies. The *scscost* was reduced to 77% of confinement costs (Conneman et al., 2008). Because of lower average SCS on pasture-based dairy farms, marginal unit increases or decreases in SCS have less economic impact.

Other $

Feet and Legs Composite. The contribution of FLC was formulated by

$$\text{FLC} = \mathit{flval} \times \mathit{lactns},$$

where *flval* is the value of better conformation for feet and legs; *flval* remained consistent with values found in NM$.

Body Size Composite. The contribution of BS was derived using the following:

$$\text{BS} = \mathit{sizekg} \times (\mathit{maint} \times \mathit{lactns} \times \mathit{actualw} + \mathit{varrepl} - \mathit{cull}),$$

where *sizekg* is the positive form of the regression of weight on body size (derived later), *maint* is maintenance costs associated with a lactating animal, *actualw* is the actual average weight, *varrepl* is the variable cost associated with raising a replacement heifer, and *cull* is the value per pound of a culled animal. Cull remains consistent with NM$ values in GM$3 for a direct comparison, but were changed in GM$1 and GM$2 to be more reflective of pasture-based conditions.

The *maint* variable was derived using 0.39 as the increased feed consumed as body size increase/kg per lactation. An 89% adjustment was made to *maint* as a confinement to grazing ratio for feed costs (Conneman et al., 2008). Additionally, maintenance cost was increased by 12% due to the assumed increase in the total amount of walking of grazing cattle. Housing costs were assumed to be $0.015, slightly less than the value from NM$ ($0.03; Table 1). The value of a heavier calf ($0.08 per lb) was subtracted from the maintenance cost (T. D. Nennich, unpublished data).

The variable *actualw* is a conversion found in NM$ adjusting mature weight to actual weight based on age. The conversion factors are in Table 2. The cull variable was updated based on beef prices for the most recent 5 yr (Gould, 2012).

The *varrepl* variable is a function of the variable replacement costs pre- and postcalving, and it is formulated as follows:

$$\mathit{varrepl} = \mathit{varrep}/1.25 + \mathit{postrep} \times (1 - 1/1.25),$$

where *varrep* is the prepartum variable replacement cost of raising a heifer and *postrep* is the postpartum variable cost of raising a heifer.

The *varrep* was calculated based on figures published in a North Dakota extension article examining the cost of grazing replacement heifers in pasture and confinement management systems (Schroeder, 2007). The per-day data were converted to a per-kilogram basis using the determination that the average grazing heifer would gain 454 kg from birth to calving, and calve at 24 mo of age. Work cited in that article discussed a $0.39/d reduced cost associated with grazing animals between 181.4 and 362.8 kg. Based on these calculations, the cost to raise a grazing heifer from birth to calving was approximately $974. Approximately 7% of the costs were fixed with the remainder being variable costs. When changed to a per-kilogram basis, the variable cost was $2.01/kg and a fixed cost (*fixrep*) of $68 per heifer. The constant of 1.25 was an age factor related to BW used in NM$ reflecting the proportion of mature BW reached by first calving. The variable *postrep* was based on a percentage of variable replacement cost denoting growth, due to maintenance cost following calving being covered under the maintenance cost variable.

The final operation weighted the proportion of mature BW the cow had yet to gain to reach its mature weight. The *sizekg* variable converts the kilogram regression to a positive number, as formulated by

$$\mathit{sizekg} = \mathit{kgreg} \times -1,$$

where *kgreg* is the regression of weight in kilograms on BS composite and was derived as follows:

$$\mathit{kgreg} = 52.9 \times \mathit{mean\ weight}/680.4,$$

where *mean weight* is the average BW of a mature cow. The constant, 52.9, is the regression coefficient of weight on the BS composite used in NM$.

The mean weight of an adult grazing cow was determined to be 590 kg. The decrease of 90.7 kg, compared with NM$, was chosen to reflect previous and current breeding practices where grazing dairy producers breed for cows of more moderate size. The 680.4 constant in the denominator represents the average Holstein cow BW representative across cows in USDA's data.

Daughter Pregnancy Rate. The weight for DPR was derived by the equation

Table 2. Derivation of actual weight by age[1]

Age (yr)	*actualm*[2]	*actualw*[3]
1	0.185	0.178
2	0.358	0.335
3	0.501	0.465
4	0.615	0.569
5	1.017	0.939

[1]Source: J. B. Cole.

[2]Proportion of mature milk reached by given age.

[3]Proportion of mature weight reached by given age.

$$\text{DPR} = \textit{dprval} \times \textit{lactns},$$

where *dprval* is the value of an increase in DPR and was calculated as follows:

$$\textit{dprval} = \textit{dprval} + 0.003 \times \textit{calfval},$$

where *calfval* is the expected value of a calf resulting from a pregnancy.

The calculation for *dprval* estimated the loss from an open day to be $2.25. This lactation value was converted to a lifetime value by multiplying by 4.5 based on the proceedings of the Western Veterinary Conference (Marshall, 2009), which reported that grazing cattle remain in the herd an average of 4.5 lactations. As in NM$, the calculation assumed no breeding attempts were made for 50% of cows experiencing their final lactation. Additionally, a heifer fertility adjustment was included, with a 0.3 correlation to cow fertility. The economic loss per day open was multiplied by 4 as a shortcut, per NM$ calculations, to convert to DPR. To account for the increased number of calves per lifetime due to DPR and decreased health expenses, $5 was added as in NM$. Morton (2004) estimated that fertility may be 3 times as important for herds with seasonal calving. Approximately 50% of grazing farmers (K. D. Gay, unpublished data) participate in some level of seasonal calving, so this economic value was multiplied by 1.5 to reflect the importance of timely calving in such systems. To convert back to a value of DPR per lactation, the economic value was divided by 4.75 (the average number of lactations adjusted for the standard deviations for PTA of PL). Also, as in NM$, 0.003 was used to account for the income resulting from an increase in calves per cow. Finally, *calfval* was set equal to $350. The increase in calf value over NM$ was to account for the increase in the value of bull calves with their value as seedstock enhanced by the more prominent use of natural-service sires by graziers.

Productive Life. The contribution of PL was calculated by

$$\text{PL} = \textit{profit} \times 0.1 + \textit{calfval} \times 0.1 \times 0.4,$$

where *profit* is equal to the value per lactation that a cow must earn to pay for itself. An approximation of 0.1 is used to convert the input value from a per-lactation basis to a per-month basis.

Profit was determined as follows:

$$\textit{profit} = -1 \times \textit{loss}/(\textit{meanPL} \times 0\ 0.1),$$

where *loss* represents the net funds lost when a cow is culled. A factor of 0.1 was used to convert the PL units from months to lactations.

$$\text{Loss} = \textit{mean weight} \times [\textit{cull} \times (1 - \textit{death}) - \textit{varrepl}] - \textit{fixrep} + \textit{cowint} \times \textit{meanPL} \times 0.1,$$

where *death* is the death rate per lifetime, *fixrep* is the fixed replacement cost, and *cowint* is the cow interest rate.

The NM$ value for death assumes that 4% of cows will die during each lactation. The death rate was multiplied by the average number of lactations accounting for standard deviations equaling the death rate for cows. The input value in NM$ is 0.2005. When the cow death rate is subtracted from the input, what remains is the heifer portion of the death rate. It was assumed that grazing cattle will experience approximately three-fourths of the death rate of confinement cattle (Burow et al., 2011). The death rates for cows and heifers were added to result in the total death rate.

Cow interest rate reflects the annual interest on funds invested in a cow per yr and is calculated as:

$$\textit{cowint} = \textit{intrate} \times (\textit{replace} + \textit{salvage})/2,$$

where *replace* equals the combined cost of replacement, *salvage* is equal to the cost recouped at culling, and *intrate* is the interest rate. The *intrate* in GM$3 remained the same as in NM$ for direct comparison; *intrate* was lowered by 0.25% to more accurately reflect the recently lower interest rates (N. J. O. Widmar, unpublished data) for GM$1 and GM$2.

Replace was calculated as

$$\textit{replace} = \textit{fixrep} + \textit{varrep} \times \textit{mean weight}/1.25 + \textit{calfval}.$$

The *replace* variable combines precalving variable costs, fixed costs, and calf value to approximate the total investment in a replacement heifer at calving.

The calculation for *salvage* provides the total investment into the cow at time of culling at mature age and is formulated as

$$\textit{salvage} = \textit{fixrep} + \textit{varrepl} \times \textit{mean weight} + \textit{calfval}.$$

Calving Ability $

The weight for CA$ remained the same as in NM$. However, the calculation of the PTA was changed to reflect the increased number of lactations, the increased calf value, and the decreased cost associated with grazing animals. Predicted transmitting abilities for GM$ were derived using the following equation:

$$PTA_{CA} = -5\ (SCE - 8) - 4\ (DCE - 8) - 8\ (SSB - 8) - 16\ (DSB - 8),$$

where constants are subtracted to adjust those evaluations to breed average. Weights for PTA_{CA} were derived for the grazing environment in parallel to those for NM$ (VanRaden, 2004; Cole et al., 2007).

Dairy Form

To account for the decrease in strength that accompanies selection against BS, an additional trait was added. Dairy form (**DF**) is a structural characteristic that encompasses body condition, openness of rib, body depth, and strength. Over time, DF has increased (narrower front-ended with very open rib), probably because of the accompanying intense selection for milk yield. That is, intense genetic selection for milk production has also resulted in cows that are narrower in the front, sharper at the withers, and carry less body condition. In a study about correlations among BCS, DF, and cow health, results showed that DF was positively correlated with overall disease incidence in the United States and negatively correlated with general disease resistance from Danish data (Dechow et al., 2004b). In addition, high DF and low BCS were correlated genetically with inferior cow health as well as with an increase in metabolic disease. Those authors concluded that selection for lower DF "may slow deterioration in health as a correlated response to selection for increased yield." Similarly for dairy cow fertility, DF was the most precise indicator of days from calving to conception (a measure of fertility) in a study about BCS and DF evaluations as they relate to days open in US Holsteins (Dechow et al., 2004a). A study of genetic relationships among type traits of Jersey cattle (Gengler et al., 1997) revealed that genetic correlations with DF were strongest for udder traits such as udder depth and rear udder height and width, and for body depth, strength, and stature. Taken together, these results suggest that selection against bulls with very high DF may be an appropriate way to retain strength while supporting higher fertility and improved health, and enhancing length of productive life.

Dairy form has a modestly negative correlation (−0.16) with strength (Dechow et al., 2003). Therefore, by placing negative selection on DF, strength could be added to the index without having to recalculate PTA. The formula used to calculate the economic weight of DF was

$$DF = BS \times 0.25/0.16.$$

To calculate the weight for DF, BS was multiplied by 0.25 based on the proportion of BW attributed to strength. This result was divided by 0.16 to account for the correlation of DF and strength.

Comparison of Index Values for Bulls

The economic weights assigned to various traits (Table 3) were multiplied by corresponding PTA (with PTA for milk, fat, and protein converted to metric values) of 584 active AI Holstein bulls from the December 2010 USDA-DHI sire summary and summed to obtain index values for GM$1, GM$2, and GM$3 for each bull. Sires were ranked for each index based on their analogous index values. Index ranks were then analyzed using PROC CORR and PROC MEANS of SAS 9.3 (SAS Institute Inc., Cary, NC).

RESULTS AND DISCUSSION

Table 4 displays the economic weights for individual traits as a percentage of each index, showing direction of selection for or against a trait. A large increase in emphasis on MY was noted in GM$1. The large difference in the weight on MY between GM$1 and GM$2 or GM$3 highlights the effect of the constraint values used in the formulation of weights for MY in NM$ and carried through to calculation of GM$2 and GM$3. The relative importance of PY in GM$1 was much less because of the greater emphasis on MY, which is strongly correlated with PY, and so does not result in greatly different progress on PY. The addition of DF in the index further contributes to decreased emphasis on many component traits of the grazing merit indices.

Daughter pregnancy rate increased in importance in all GM$ indices. This arose from the increase in the average number of lactations and also the adjustment of the importance of DPR due to the prevalence of seasonal calving in grazing operations. A small decrease in the importance of BS occurred due to a shift of emphasis in the traits. A large decrease in the emphasis on PL in the GM$ indices was detected because the loss incurred from culling is much smaller for grazing cattle, because rearing costs of replacements are less and returns are spread over more lactations. Further, the longer PL of cattle in grazing management systems decreases the marginal value of further increases in PL compared with that needed for confinement management systems in NM$. As noted, most other changes were likely attributable to the addition of DF, which received 6% of the emphasis in the index, thereby slightly reducing the emphasis on other traits. Differences between GM$2 and GM$3 were small and seen in emphasis on PL and BS.

Table 3. Genetic standard deviations (SD) and selection index weights for traits included in Grazing Merit$ 1 (GM$1), Grazing Merit$ 2 (GM$2), Grazing Merit$ 3 (GM$3), and USDA Net Merit$ (NM$)

Trait	SD[1]	GM$1	GM$2	GM$3	NM$[1]
Milk yield (kg)	327.95	0.4663	0.0040	0.0040	0.0022
Fat yield (kg)	12.25	8.4028	9.8215	9.8215	6.3713
Protein yield (kg)	8.62	3.0686	11.6072	11.6072	7.5177
Udder composite (SD)	0.90	49.5000	49.5000	49.5000	32.000
SCS ($\log_2$)	0.23	−234.315	−234.315	−234.315	−182.000
Feet and leg composite (SD)	1.03	22.5000	22.5000	22.5000	15.000
Daughter pregnancy rate (%)	1.70	66.8250	66.8250	66.8250	27.000
Body size composite (SD)	1.03	−20.6063	−20.6063	−21.0410	−23.000
Productive life (mo)	2.50	18.8160	18.8160	15.7093	35.000
Calving ability$ ($)	20.00	1.0000	1.0000	1.0000	1.000
Dairy form (SD)	1.14	−32.1970	−32.1970	−32.1970	0.000

[1]Source: J. B. Cole (USDA, Beltsville, MD, personal communication).

It is widely held that grazing producers desire cows that are smaller in stature but have great dairy strength and body capacity, especially in width of the chest and spring of rib. The addition of DF to the index was due to its fairly strong negative correlation with strength (Dechow et al., 2003). By selecting against DF, the decrease in capacity from the selection against body size composite was offset.

Table 5 contains a comparison of index traits and the proportions of each index from this study and several existing indices. Traits were grouped into 3 categories: production traits, health and reproductive traits, and durability traits. Traits reflected in Table 5 are those related to NM$ traits of MY, FY, and PY for production; FLC, UC, PL, and BS for durability; and SCS, CA, and DPR for health and reproductive traits. Compared with the index of Rozzi et al. (2007) based on producer-assigned trait values for organic dairy production in Canada, there was a large increase in the value placed on production traits in GM$1. This is likely due to the more historically accurate weight on MY in GM$1. It may also reflect some differences in value of increasing milk yield under a supply management system, as is the case for Canada. Additionally, the value of a one-unit increase in MY is economically greater in a grazing environment than a value of a one-unit shift in a favorable direction of another trait. The Rozzi et al. (2007) index was based upon producer preference, and maximizing profit was not the goal of the index, as it was in GM$1. Substantially less of the index is devoted to production traits compared with the New Zealand Breeding Worth index (Montgomerie, 2002), which also includes a substantially lower emphasis on health and reproductive traits. It is important to note that a large percentage of the Irish and New Zealand indices are dedicated to the reduction of milk volume (12 and 17%, respectively; Montgomerie, 2002; ICBF, 2012).

The Spearman rank correlations for GM$1, GM$2, and GM$3 and the existing US indices are displayed in Table 6. Comparisons of the indices reveal that GM$1 had the highest correlation with Fluid Merit$ (0.96) and the lowest with Cheese Merit$ (0.86). This is likely attributed to the nonrestricted weight on MY and lower value for protein. Conversely, GM$2 had the highest correlation with NM$ (0.98) and lowest with Fluid Merit$ and GM$1 (0.94), likely because GM$2 shares yield values with NM$, thereby restricting the value of MY; GM$3 displayed the highest correlation with

Table 4. Selection index weights as percentage of index for Grazing Merit$ 1 (GM$1), Grazing Merit$ 2 (GM$2), Grazing Merit$ 3 (GM$3), and USDA Net Merit$ (NM$)[1]

Trait[1]	GM$1	GM$2	GM$3	NM$
Milk yield (kg)	24	0	0	0
Fat yield (kg)	16	21	21	19
Protein yield (kg)	4	17	17	16
Udder composite (SD)	7	8	8	7
SCS ($\log_2$)	−8	−9	−9	−10
Feet and leg composite (SD)	4	4	4	4
Daughter pregnancy rate (%)	18	20	20	11
Body size composite (SD)	−3	−4	−4	−6
Productive life (mo)	7	8	7	22
Calving ability$ ($)	3	3	3	5
Dairy form (SD)	−6	−6	−6	0

[1]Absolute values of numbers do not necessarily add to 100 due to rounding error.

Table 5. Comparison of additive relative weight proportions

Index	Production	Durability	Health and reproduction
Grazing Merit$ 1	44	27	29
Grazing Merit$ 2	38	30	32
Grazing Merit$ 3	38	30	32
US Net Merit$[1]	35	39	26
Canadian Organic[2]	28	47	25
New Zealand Breeding Worth Index[3]	64[4]	25	10
Irish Economic Breeding Index[5]	38[4]	25	36

[1]Source: Cole et al. (2010).

[2]Source: Rozzi et al. (2007).

[3]Source: Montgomerie (2002).

[4]A negative weight is applied to selection for milk production, which cancels some of the weight for protein production.

[5]Source: ICBF (2010).

GM$2 (1.00). Despite high correlations with NM$ (0.93 and 0.98 for GM$1 and GM$2 or GM$3, respectively), both correlations were equal to or less than those found between NM$ and Fluid Merit$ and Cheese Merit$ (0.97 and 0.98, respectively). Although a high correlation was found between the existing US indices, the addition of Fluid Merit$ and Cheese Merit$ were deemed beneficial to reflect differences in regional milk market conditions. Based on this precedent, GM$1, GM$2, or GM$3 may have merit as an index specifically dedicated to grazing dairies, despite relatively high correlations with those already in existence.

Table 7 gives descriptive statistics for rank changes among the indices for 584 active AI bulls of the Holstein breed. As expected, the greater average changes in ranks occurred between the less correlated indices. For GM$1, the average change in rank from NM$ was 47.76 with a SD of 42.76, a minimum change of 0, and a maximum change of 251 positions in rank. The average change in rank of GM$2 from NM$ was 26.02 with an SD of 22.93, a minimum change of 0, and a maximum change of 122. For GM$3, the average change in rank was 27.34, with a standard deviation of 24.02, a minimum change of 0, and a maximum change of 127. The data suggest that the majority of changes in rank were small; however, some large changes did occur. This suggests that although NM$ can provide a reasonable approximation of grazier needs, depending on the selection criteria used, such as choosing only the top-desired percentile of bulls, the best bulls for graziers will not always be chosen using that criteria.

Today's population of AI Holstein bulls possess genetic characteristics that can perform well in both NM$ and an index designed primarily for grazing dairies. However, selection of bulls using an index weighted to reflect the needs of pasture-based producers could yield genetic progress dramatically different from that based on continued use of current indices.

Estimates of genetic progress for individual traits comprising the NM$ and the grazing indices are found in Tables 8 and 9. Table 8 shows the annual genetic progress of the PTA, whereas Table 9 contains the genetic progress of the EBV after 10 yr of selection on the overall index. Compared with the genetic progress of NM$, GM$1 had more progress for MY and PY, as expected given the increased value of these traits when historic numbers are used for milk prices. There was a 2-mo loss in the rate of expected increase over 10 yr of selection for PL using GM$1, arising from the diminishing returns of increasing that trait in a grazing environment. Nevertheless, even selection with GM$1 resulted in a 6.7-mo increase in the length of PL. A de-

Table 6. Spearman rank correlations for Net Merit$ (NM$), Cheese Merit$ (CM$), Fluid Merit$, Grazing Merit$ 1 (GM$1), Grazing Merit$ 2 (GM$2), and Grazing Merit$ 3 (GM$3)[1]

	NM$	CM$	FM$	GM$1	GM$2	GM$3
NM$	1.00	0.98	0.97	0.93	0.98	0.98
CM$		1.00	0.90	0.86	0.97	0.96
FM$			1.00	0.96	0.94	0.94
GM$1				1.00	0.94	0.94
GM$2					1.00	1.00
GM$3						1.00

[1]Calculated for 584 active Holstein AI bulls using USDA and Holstein USA genetic evaluations.

Table 7. Absolute rank change differences between Grazing Merit$ 1 (GM$1), Grazing Merit$ 2 (GM$2), and Grazing Merit$ 3 (GM$3) compared with Net Merit$ (NM$), Cheese Merit$ (CM$), and Fluid Merit$ (FM$)[1]

Difference	Mean	SD	Minimum	Maximum
GM$1 vs. NM$	47.76	42.76	0	251
GM$1 vs. CM$	69.21	58.60	0	324
GM$1 vs. FM$	34.49	30.74	0	154
GM$2 vs. NM$	26.02	22.93	0	122
GM$2 vs. CM$	32.81	29.23	0	161
GM$2 vs. FM$	42.88	38.73	0	213
GM$3 vs. NM$	27.34	24.02	0	127
GM$3 vs. CM$	33.52	30.00	0	166
GM$3 vs. FM$	43.78	39.42	0	214

[1]Bulls included 584 Holstein AI sires from the USDA/DHI December 2010 sire summary.

cline in rate of improvement of DPR (Table 9) was seen in GM$1 compared with other indices due to the strong negative correlation with MY and the greater emphasis on MY in GM$1. Use of the GM$2 index would lead to the greatest increase in DPR as well as a larger reduction in DF (Table 9). The extra genetic progress of DF and DPR in the GM$2 index, however, comes at the price of a steep reduction in genetic progress for production traits compared with the NM$ index. Progress made in GM$3 was similar to that made in GM$2 for all traits.

Currently, there are 584 active US Holstein AI sires. The common recommendation is to select from the top 10% of AI bulls available. This approach means that producers wishing to follow expert recommendations have only about 58 AI bulls to select from. Based on this study, the average change in rank for the GM$ indices from the current indices is 48. Such a significant change in rank suggests that grazing producers selecting from the current top 10% will likely not be selecting bulls that are optimal for their selection criteria. Coupled with the significant differences in genetic progress between GM$2 and NM$, a strong case exists for the benefit of a grazing merit index to select among US AI bulls, but without the need for a separate progeny-testing program for grazing herds.

CONCLUSIONS

Current selection indices do not emphasize the same traits that are preferred by US graziers. Therefore, 3 grazing merit indices were constructed for grazing production in the United States. This project examined how currently available indices compared with those specifically designed for pasture-based production systems. Precedence exists for the establishment of new indices, despite correlations that are similar to those between NM$ and GM$1, GM$2, and GM$3. Thus, the establishment of a grazing merit index would provide graziers with an option more closely meeting their need for specialized selection criteria. Additionally, the weights as a percentage of the index show that, over time, bulls that satisfy both NM$ and GM$ may diverge because of an increased emphasis on milk yield (in GM$1), a greater significance for reproduction, a decreased need for productive life, and an interest in selecting for capacity but not stature. The possibility of divergence is further illustrated by the calculations for genetic progress, which emphasize reproduction at the expense of production. An improved grazing merit index might also include traits that are of specific interest to grazing dairies, such as grazing ability (which includes bites per minutes and muzzle width), heat tolerance, and milking speed. Based on these results,

Table 8. Annual genetic progress of PTA Grazing Merit$ 1 (GM$1), Grazing Merit$ 2 (GM$2), Grazing Merit$ 3 (GM$3), and Net Merit$ (NM)

Trait	GM$1	GM$2	GM$3	NM$
Milk yield (kg)	37.419	18.526	18.376	25.524
Fat yield (kg)	1.230	1.266	1.261	1.346
Protein yield (kg)	1.000	0.817	0.812	0.900
Productive life (mo)	0.335	0.356	0.341	0.443
SCS (log_2)	−0.012	−0.016	−0.015	−0.018
Body size composite (SD)	−0.041	−0.039	−0.038	−0.050
Udder composite (SD)	0.012	0.021	0.020	0.037
Feet and leg composite (SD)	0.017	0.020	0.019	0.028
Daughter pregnancy rate (%)	0.110	0.142	0.137	0.117
Calving ability$ ($)	1.940	1.957	1.909	2.171
Dairy form (SD)	−0.012	−0.071	−0.070	−0.029

Table 9. Genetic progress of breeding values over a 10-yr period for Grazing Merit$ 1 (GM$1), Grazing Merit$ 2 (GM$2), Grazing Merit$ 3 (GM$3), and USDA Net Merit$ (NM$)

Trait	GM$1	GM$2	GM$3	NM$
Milk yield (kg)	339.465	168.069	166.703	231.553
Fat yield (kg)	11.157	11.490	11.439	12.214
Protein yield (kg)	9.076	7.412	7.366	8.165
Productive life (mo)	6.700	7.121	6.815	8.862
SCS ($\log_2$)	−0.243	−0.311	−0.300	−0.365
Body size composite (SD)	−0.816	−0.781	−0.768	−0.991
Udder composite (SD)	0.235	0.428	0.393	0.746
Feet and leg composite (SD)	0.350	0.399	0.373	0.562
Daughter pregnancy rate (%)	2.204	2.848	2.741	2.343
Calving ability$ ($)	38.799	39.134	38.178	43.423
Dairy form (SD)	−0.240	−1.411	−1.396	−0.584

sufficient evidence exists to justify the use of a grazing index to meet the specific selection needs of pasture-based dairy farms.

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APPENDIX

Original NM$ Equations

$$\text{NM\$} = \text{Yield\$} + \text{Udder\$} + \text{Other\$} + \text{CA\$}$$
$$\text{Yield\$} = \text{MY} + \text{PY} + \text{FY}$$
$$\text{MY} = (milkval - milkfeed - milkhealth) \times lactns$$
$$\text{PY} = (protval - protfeed - prothealth) \times lactns$$
$$\text{FY} = (fatval - fatfeed - fathealth) \times lactns$$
$$lactns = mean\ PL \times 0.1$$
$$\text{Udder\$} = \text{UC} + \text{SCS}$$
$$\text{UC} = uddval \times lactns$$
$$\text{SCS} = scsval \times lactns$$
$$scsval = scsprem \times mean\ MY - scscost$$
$$\text{Other\$} = \text{FLC} + \text{BS} + \text{DPR} + \text{PL}$$
$$\text{FLC} = flval \times lactns$$
$$\text{BS} = sizekg \times (maint \times lactns \times actualw + varrepl - cull)$$
$$sizekg = kgreg \times -1$$
$$kgreg = 52.9 \times mean\ weight/680.4$$

$\text{DPR} = dprval \times lactns$
$dprval = dprval + 0.003 \times calfval$
$\text{PL} = profit \times 0.1 + calfval \times 0.1 \times 0.4$
$profit = -1 \times loss/(mean\ PL \times 0.1)$
$loss = mean\ weight \times [cull \times (1 - death) - varrepl]$
$\quad - fixrep + cowint \times mean\ PL \times 0.1$
$varrepl = varrep/1.25 + postrep \times (1 - 1/1.25)$
$cowint = intrate \times (replace + salvage)/2$
$replace = fixrep + varrep \times mean\ weight/1.25$
$\quad + calfval$
$salvage = fixrep + varrepl \times mean\ weight + calfval$