<https://helda.helsinki.fi>

Variation in the actual preferences for AI bull traits among Finnish dairy herds

Paakala, Elina

2018-12

Paakala , E , Martin-Collado , D , Mäki-Tanila , A & Juga , J 2018 , ' Variation in the actual preferences for AI bull traits among Finnish dairy herds ' , Journal of Animal Breeding and Genetics , vol. 135 , no. 6 , pp. 410-419 . <https://doi.org/10.1111/jbg.12359>

<http://hdl.handle.net/10138/322023>

<https://doi.org/10.1111/jbg.12359>

unspecified

acceptedVersion

Downloaded from Helda, University of Helsinki institutional repository.

This is an electronic reprint of the original article.

This reprint may differ from the original in pagination and typographic detail.

Please cite the original version.

Variation in the actual preferences for AI bull traits among Finnish dairy herds

Journal:	<i>Journal of Animal Breeding and Genetics</i>
Manuscript ID	JABG-18-0015.R2
Manuscript Type:	Original Article
Date Submitted by the Author:	04-Sep-2018
Complete List of Authors:	Paakala, Elina; Helsingin Yliopisto Maatalous-Metsätieteellinen Tiedekunta, Animal Science; Faba co-op Martin-Collado, Daniel; Centro de Investigacion y Tecnologia Agroalimentaria de Aragon Mäki-Tanila, Asko; University of Helsinki, Department of Agricultural Sciences Juga, Jarmo; University of Helsinki, Animal Science
Subject Area:	artificial insemination, breeding goal, dairy cattle, selection index, breeding programme

SCHOLARONE™
Manuscripts

Variation in the actual preferences for AI bull traits among Finnish dairy herds

Elina Paakala ^{1,2}, Daniel Martín-Collado³, Asko Mäki-Tanila¹ and Jarmo Juga¹

¹Department of Agricultural Sciences, University of Helsinki, PO Box 28, 00014 Helsinki, Finland

²Faba co-op, Urheilutie 6D, 01370 Vantaa, Finland

³Centro de Investigación y Tecnología Agroalimentaria de Aragón, Avda. Montañana 930, 50059 Zaragoza, Spain

Abstract

Changing production circumstances, a wide range of traits and the international bull market enable dairy farmers to make increasingly specific choices concerning artificial insemination (AI) bulls. Finland is part of the joint Nordic dairy cattle breeding programme where in addition to yield, high emphasis is given to health, fertility, conformation and longevity. The aims of our study were (1) to investigate whether Finnish dairy farmers differ in their selection preferences for AI bull traits and can be clustered into herd groups, (2) to determine whether AI bull selection in different herd groups is in line with the Nordic total merit index (NTM) and (3) to analyse how the herd groups are related to herd characteristics. We used a statistical cluster analysis to analyse AI bull usage and to group herds according to each herd's bull selection profile determined by the traits' estimated breeding value (EBV) mean weighted by the number of inseminations for the various traits. We identified four herd groups in both Ayrshire (AY) and Holstein (HOL) breeds: Production, Fertility, All-rounders, and Conformation. The herds' bull selection profiles were mostly close to the NTM except in the Conformation herd groups where traits other than conformation were nearly neglected. This led to poorer expected genetic and economic outcomes than with the

NTM selection. Conformation herds were a minority, but they were larger in herd size and investments had recently been made. The data suggest that either fine-tuning the weights in the NTM, forming alternative indices or developing a herd-specific total merit index (TMI) could fulfil the needs of very diverse herds.

Keywords: Artificial insemination, breeding goal, breeding programme, dairy cattle, selection index

Introduction

Finland, Denmark and Sweden have had a joint dairy cattle breeding programme since 2002 for the Nordic Red Breeds (Finnish Ayrshire (AY), Swedish Red and Danish Red), Holstein (HOL) and Jersey. The programme is coordinated by the artificial insemination (AI) organization Viking Genetics and the breeding values are computed by Nordic Cattle Genetic Evaluation (NAV; Aarhus, Denmark). The joint Nordic breeding programme is based on the breed-specific Nordic Total Merit index (NTM), which guides population-level AI bull selection. Traits incorporated in the NTM are weighted according to their economic importance in the Nordic production environment (Kargo et al., 2014). In addition, farmer representatives annually reassess the weights to reflect farmer opinions, societal needs, and consumer preferences (Table 1). Yield, longevity, fertility, and health traits have always had the highest emphasis in the NTM.

National breeding goals have traditionally guided dairy farmers' bull selection in the three Nordic countries. More recently, this has been taken up by the NTM. In Finland, the majority of AI doses are purchased from the joint Nordic breeding programme, but the quantity of annually imported AY and HOL semen doses has notably increased in past years and is becoming quite relevant. In 2015, 10% of the total AY breed doses (approx. 280 000, Animal Health ETT, 2016) and 30% of the HOL breed doses (approx. 230 000 sold doses) were imported from outside of the three Nordic countries carrying out the joint dairy cattle breeding programme.

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

56 The Finnish dairy sector has recently experienced major changes. Since 2000, the
57 number of dairy herds has more than halved, while the total quantity of milk received
58 by dairies has remained essentially unaltered (Ahlstedt et al., 2015). The average
59 size of a milk-recorded dairy herd has more than doubled from 17.1 to 36.0 cows
60 (ICAR, 2016). In the meantime, the exploitation of reproduction technologies and the
61 rapid implementation of genomic selection have altered dairy breeding programmes
62 across the globe. Also, the use of automatic management has increased in various
63 stages of dairy production, and is consequently changing the profile of traits desired
64 in a dairy cow. For example, Germany utilizes an index to describe the suitability of a
65 bull's daughters to automatic milking systems (vit IT-Solutions for Animal Production,
66 2016).

67 Under the changing and varied production sector, the wide international market for
68 dairy bulls and the increasing number of traits being evaluated, farmers' trait
69 preferences are segmented and farmers can be grouped according to their various
70 trait preferences (e.g. Martin-Collado et al., 2015; Slagboom et al., 2016). As a
71 response to the heterogeneity in dairy farmers' trait preferences, many breeding
72 associations and companies are developing a series of total merit indices (TMI)
73 instead of just one common index, to meet specific farmer needs and preferences.
74 For example, three indices (Balanced Performance Index, Health Weighted Index,
75 and Type Weighted Index) have been introduced to the Australian dairy sector.
76 These three indices are based on a combination of bio-economic analysis, a farmer
77 preferences' survey, and a desired gain approach (Martin-Collado et al., 2015; Byrne
78 et al., 2016).

79 The analysis of farmers' trait preferences can be used to strengthen farmer
80 participation in a breeding programme. Nielsen et al. (2014) argued that including
81 farmer's views in deciding the level of trade-off between production and functional
82 traits, may enhance his or her endorsement of the breeding objectives. The implicit
83 weighting of the traits deduced from farmers' purchase behaviour were included in
84 the analysis of a breeding goal to find out how much farmers were willing to sacrifice
85 in the selection response for production traits in to improve functional traits related to

sustainability (Nielsen et al., 2005). The results showed that further genetic improvement, for e.g. functional traits, was possible by including nonmarket values (e.g. animal wellbeing and environmental impact), which were independent of current market forces in the breeding goal with only minor losses in total selection response.

When extensive national insemination records are available, they can be used to quantify the genetic and economic effect of farmers' choices among the traits when selecting AI bulls to breed their cows. Alfonso (2016) used U.S. Holstein dairy cattle insemination data to demonstrate the use of a discrete Choquet integral, an averaging aggregation function defined with respect to a fuzzy measure (e.g. Beliakov et al. 2016) in constructing an aggregate breeding goal genotype. In this method the stated preferences of decision makers are expressed as predicted breeding values of animals and the number of offspring can be considered as "realized preference" of the aggregate goal.

Analysing stated preferences (i.e. what farmers say they prefer) has to date been the main approach for investigating farmers' trait preferences, which is the only possible approach if sufficient data on the used bulls are not available (e.g. Nielsen and Amer 2007; Martin-Collado et al., 2015; Slagboom et al. 2016). However, the stated preferences' approach has certain weaknesses as we do not know how well they lead to realized choices. However, this problem can be overcome to some extent with a sound experimental design if there are enough data to analyse the realized choices (i.e. revealed preferences). For example, the stated preferences concerning consumer interests in buying a product have been seen to differ from realized choices (Morwitz, 2014). In the case of AI bulls, the difference between intention and purchase may stem e.g. from the price and availability of semen doses and the marketing strategies of breeding companies.

In Finland, there are extensive data on herd characteristics, insemination records and AI bulls' estimated breeding values (EBVs) for a wide range of traits. The actual use of AI bulls extracted from the insemination data in our current study can provide useful information on farmers' actual purchase behaviours. We analysed the data

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15

115 with the objectives of our study being (1) to investigate whether Finnish dairy farms
116 have differing selection preferences for AI bull traits and can be clustered into herd
117 groups, (2) to determine whether AI bull selection in different herd groups is in line
118 with the NTM of the joint Nordic breeding programme and (3) to analyse how the
119 herd groups differ in herd characteristics.
120

16
17
18
19
20

121 **Materials and methods**

21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40

122 *Data*

41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

123 The analysis was based on insemination data provided by the breeding organization
124 Faba co-op (Hollola, Finland). Specifically, we analysed AY and HOL AI bull
125 inseminations of Finnish milk-recording herds in 2015. AY and HOL are the main
126 dairy breeds in Finland, constituting 55.0% and 43.3% of the total number of milk-
127 recorded cows in 2015, respectively. The dataset included 475 015 insemination
128 records from 5 987 herds. The quantity of AI doses imported from outside Finland,
129 Denmark, and Sweden was quite substantial (Animal Health ETT, 2016). A total of 27
130 790 AY semen doses were imported in 2015, with 21 323 doses used in the 2015
131 inseminations (11% of all AY semen doses used in Finnish milk-recording herds).
132 The number of imported HOL semen doses was 66 384, just over half (37 999) of
133 which were used in inseminations during that same year (22% of all HOL semen
134 doses used in Finnish milk-recording herds).

135
136
137
138
139
140
141
142

135 As an essential basis for our study, the insemination data were combined with bull
136 EBV information. The EBVs from the November 2015 evaluation (provided by NAV)
137 of the 14 traits included in the NTM (Table 1) were used in the analysis. AI bulls used
138 for less than 100 inseminations were excluded from the dataset, as were also the
139 bulls with missing EBVs; EBVs were missing for 31 AY and 41 HOL bulls. The
140 excluded bulls of both breeds were young bulls mostly from North America that had
141 been genomically evaluated in their birth country but not in the Nordic setting. The
142 final data set included 176 AY bulls and 232 HOL bulls. The number of inseminations

per bull varied considerably: 67 bulls of both breeds were used more than a thousand times, with the most popular AY and HOL bull being used 8 767 and 7 529 times, respectively, while 41 AY bulls and 85 HOL bulls were only used 100–200 times.

As Finnish dairy herds often have cows from more than one breed, we wanted to explore breed-specific bull selection. We therefore analysed the herd data separately for AY and HOL breeds by only considering herds with more than 90% of the cows of either breed. After filtering, the final data set consisted of 1 279 AY herds (70 158 inseminations) and 544 HOL herds (34 512 inseminations).

ProAgria (the Association of ProAgria Advisory Centres; Vantaa, Finland) provided herd characteristics data from 2015. We analysed 23 herd characteristics: herd size, average energy-corrected milk yield, average yield (cows and heifers), lifetime yield (live and culled cows), number of calvings per cow, calving age of heifer, calving interval, number of inseminations (cows and heifers), culling percentage (cows and heifers), cow mortality, percentage of stillborn calves, animal density per hectare of arable land, investment year of cow housing, average NTM of cows (including all cows and breeds of the herd), housing type, feeding type, milking machine type, agricultural subsidy region in Finland and whether the farm is conventional or organic (Table S3; Table S6).

Statistical analysis

A cluster analysis (CA) was performed to investigate whether the herds formed clear groups based on their bull selection profiles. To summarize a farmer's revealed preferences for AI bull traits, we defined a "herd bull selection profile" as the average of all 14 trait EBVs available for the bulls over all the inseminations in the herd. The CA was performed using R software and the k-means clustering method (MacQueen, 1967; R Core Team, 2016). The k-means clustering method is one of the most popular methods for partitioning a large number of observations into k clusters based on some descriptive variables. The goal is to minimize the intra-cluster distances between variables values (here the average sire traits EBVs), while maximizing inter-cluster distances (Ghatak, 2017). The number of clusters (k) in this method is pre-

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

determined. Starting with a set of randomly chosen data points as initial centres an algorithm is repeated where each data point is placed to the cluster whose centre value is closest to the data point. The centre value is replaced with a new mean until the solution does not change between two consecutive rounds. The clustering will result in the pre-determined number of herd groups resembling each other and differing from other groups with respect to herd bull selection profiles. The decision concerning the most appropriate number of clusters was based on a comparison of loss of inertia (within-cluster sum of squares) at each partitioning of clusters and on the statistical testing of differences among the emerged clusters for the variables considered.

The CA was performed separately for the AY and HOL herds. The analyses were run by varying k from two to five. The statistical significance for the differences in each traits' average sire EBV between the herd clusters was tested using ANOVA with a subsequent Tukey's multiple comparison test for pairwise differences (Tukey, 1949). Four was the most meaningful number of herd clusters ("herd groups" hence forward) for both AY and HOL breeds based on the aforementioned criteria. Separate CAs were also implemented for herds where 40-60% of cows were either AY or HOL breed to explore how such herds possibly differed from the previous "pure" herd results.

The average sire EBV for the 14 traits in the herd groups shows the selection differential and the expected genetic gain and further the subsequent economic change in the next generation resulting from the AI bull selection. For comparison, we also calculated the expected selection differential resulting from NTM based bull selection for both breeds. In the Nordic breeding programme three percent of the 3 000 genomically tested bulls are annually selected for semen production in both breeds (VikingGenetics, 2016a, 2016b). This corresponds to a selection intensity of 2.27. The expected selection differential resulting from the NTM based bull selection for each 14 NTM trait was calculated based on the selection intensity, and the genetic correlation between each trait and NTM (Nordic Cattle Genetic Evaluation, 2016). Most recent genetic correlations and economic values were used in the

analysis. The EBV for youngstock survival was not available until 2016 and was therefore omitted from the analyses, which were based on AI bulls' EBVs from November 2015.

The economic consequences of bull selection were computed using the most recent economic values per index point estimated for the 14 NTM traits (Carlén et al., 2016). For each trait, the EBV's deviation from 100 (EBVs are published with a mean of 100 and an s.d. of 10) was divided by 2 (to calculate the value of predicted transmitting ability of the sire, assuming average dams) and multiplied by the economic value of the trait per index point. The sum of the economic values across the traits was used to express the overall economic impact of bull selection in the herd groups and, for comparison, of the NTM selection.

We analysed the herd characteristics in the AY and HOL herd groups. An average was calculated for each group for continuous herd characteristics, while an occurrence percentage was calculated for categorical herd characteristics. The statistical significance of the differences among the four herd groups was tested for each farm characteristic using ANOVA with a subsequent Tukey's multiple comparison test for pair wise differences among the groups. The chi-squared test was used to test for differences in the categorical variables.

Results

Both AY and HOL pure herds exhibited clearly differentiated herd's bull selection profiles, with quite similar herd groups in the two breeds.

Ayrshire herds' bull selection profiles

- Group 1: **Production herds**. A total of 452 herds, whose farmers had the highest preference for yield and growth in the bull selection compared to other herd groups (Figure 1). Farmers in this group, along with Fertility herd farmers, also favoured milkability and temperament more highly than farmers in the

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

229 other two groups. Production herd farmers paid the least attention among the
230 groups to udder conformation.

231 - Group 2: **Fertility herds**. A total of 393 herds, whose farmers preferred
232 fertility, calving traits, other diseases, longevity (Figure 2) and feet and leg
233 conformation (Figure 3) more than farmers in the other groups.

234 - Group 3: **All-rounder herds**. A total of 377 herds, whose farmers focused
235 evenly on all traits. Udder conformation was the only exception to this, as it
236 was emphasized the second highest by All-rounder farmers (Figure 3).
237 Farmers in the all-rounder herds, as well as in the Fertility herds, preferred to
238 use AI bulls with high EBVs for udder health.

239 - Group 4: **Conformation herds**. A total of 57 herds. Farmers in this group
240 focused mostly on udder conformation, frame and claw health (Figure 3), and
241 tended to select bulls with very low EBVs for all other traits. The average
242 EBVs for yield, growth, fertility, other diseases, milkability and temperament of
243 selected bulls' were below the current population average.

244 Production, Fertility, and All-rounder herds' farmers' selected AI bulls in a rather
245 similar manner. Bull selection in these three groups was close to NTM-based
246 selection but with less focus placed on yield and growth, and slightly more on fertility,
247 udder conformation, milkability and temperament. On the contrary, farmers' bull
248 selection in the Conformation herds deviated substantially from the NTM selection;
249 these farmers gave far less importance to yield, growth, and longevity than in the
250 NTM selection, while focusing more on frame and udder conformation. The
251 Production, Fertility and All-rounder herd groups were quite equal in their share of
252 herds (29.5–35.3%) and inseminations (29.2–36.6%) (Table 2). The Conformation
253 herd group was much smaller, representing 4.5% of herds and 2.2% of
254 inseminations.

255 Results for the usage of AY bulls in mixed herds (Table S2) were very similar with
256 pure herd results: most mixed herds belonged to either Production herds (380 herds)
257 or Fertility herds (392 herds). These two groups, along with the Conformation group
258 (56 herds), were very similar with the pure herd groups in their bull selection profile

(Table S1). The fourth group (conformation+, 37 herds) was an exception. In this group conformation was highly emphasized together with yield, health, fertility, longevity and milkability where as in the Conformation group other traits than conformation were neglected. No All-rounder herd group was formed among the mixed AY herds.

The expected economic impact resulting from NTM-based bull selection in AY bulls' daughter's lifetime performance was € 102.7. In the first three herd groups this figure was very similar to the NTM-implied economic impact: € 98.9 (-3.7% compared to NTM selection) per cow for Production herds, € 103.0 (+0.3%) for Fertility herds, and € 100.2 (-2.4%) for All-rounder herds. The per-cow economic change for Conformation herds was negative: € -20.8 (-120.3%).

Conformation herds averaged the largest herd size and highest animal density per hectare of arable land (Table S3). Farmers in this group had made investments on their farms approximately ten years later than farmers in the other groups.

Conformation herds also more commonly utilized a loose-housing system, a mixed ration feeding system, and an automatic milking system. Conformation and All-rounder herds had cows with the highest average yield. All the yield-related herd characteristics were lowest in Production herds (statistically significantly different from All-rounder and Conformation herds). The calving interval in All-rounder herds (411.8 d) was somewhat shorter than in the other groups (420.8–422.0 d). The average herd NTM (calculated using the herd characteristics data, including all cows of all breeds in the herd) was lowest for Conformation herds (-6.33) and highest for All-rounder herds (0.80), with no statistically significant difference from the Fertility herds (0.18).

Holstein herds' bull selection profiles

Similarly to the AY herds, the HOL herds formed four groups with similar emphasis in bull selection (Table S4):

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

- Group 1: **Production herds**. A total of 169 herds, whose farmers emphasized yield and growth more than farmers in the other herd groups (Figure 1). They also highly emphasized longevity.
 - Group 2: **Fertility herds**. A total of 280 herds, whose farmers tended to select bulls with high EBVs for fertility, longevity (Figure 2) and health traits.
 - Group 3: **All-rounder herds**. A total of 48 herds, whose farmers focused evenly on all the traits in their bull selection. Milkability was most emphasized in this herd group (Figure 1).
 - Group 4: **Conformation herds**. A total of 47 herds, whose farmers favoured frame, udder conformation, and temperament in their bull selection (Figure 3). These farmers used bulls with a very low average EBV for all other traits, in particular for fertility (Figure 2) and health traits. The EBVs of the bulls used in this group were below the current population average for these two traits.
- Udder conformation and frame were emphasized more in all the herd groups than in the NTM selection. The largest negative deviations from NTM selection in the Conformation herds occurred in fertility, health and longevity traits. Overall, Production and Fertility herds deviated least from the NTM selection. Half of the herds were categorized as Fertility herds, one-third as Production herds (Table 2) and both the All-rounder and Conformation herd groups each contained approximately one tenth of the herds. The usage of HOL bulls in the mixed herds (in which 40-60% of the cows were HOL breed) (Table S5) was very similar to that in pure HOL herds (Table S4). Most mixed herds belonged to either Production herds (328 herds) or Fertility herds (420 herds). All-rounders (49 herds) and Conformation herds (76 herds) were smaller groups.
- The expected economic impact in the next generation due to the NTM-based bull selection was € 123.8 for a HOL daughter's lifetime performance. The expected economic impact in the next generation due to bull selection was larger for Fertility and Production herds than in the NTM selection: € 141.1 (+14.0% compared to NTM selection) per cow in the Fertility herds and € 140.8 (+13.7%) in Production herds.

315 The economic impact was slightly lower in the All-rounder herds (€ 117.4, -5.2%) and
316 even lower in the Conformation herds (€ 46.5, -62.4%).

317 All-rounder and Conformation herds in the HOL breed averaged the largest in size
318 among the herd groups, with highest animal density per hectare of arable land and
319 the most recent investments (Table S6). The herds in these two groups more often
320 incorporated loose housing, mixed ration feeding and automatic milking, and had
321 higher average yield per cow and heifer than in the Fertility and Production herds.
322 Production, Fertility, and Conformation herds had the highest lifetime yield for culled
323 cows. Cow mortality was the highest in Conformation herds. Conformation herds had
324 the lowest (-3.32) and Production herds the highest (0.26) average herd NTM
325 (including all breeds), with the latter having no statistically significant difference
326 compared to the All-rounder herds.

327

328 Discussion

329 *Main findings*

330 We analysed the variation in AI bulls usage in Finnish dairy herds with over 90% of
331 the cows being either of the two main dairy breeds (AY and HOL). Using CA for the
332 AI bulls' traits EBVs, we were able to identify different herd groups. The same set of
333 four groups emerged in both breeds: Production, Fertility, All-rounder and
334 Conformation. Production, Fertility and All-rounder herds bull selection profiles
335 deviated rather slightly from the NTM and the differences between these three
336 groups were relatively small compared to how these groups deviated from the
337 Conformation groups. The Conformation groups had a low number of herds, while
338 they averaged the largest herds and the most recent investments. A tendency for the
339 production traits was exhibited, where herds with lower average yield favour bulls
340 with high yield EBV. On the other hand, herds with higher means, in the
341 Conformation group in particular, chose bulls with low EBVs in production traits when
342 concentrating on selecting bulls with high EBVs on conformation traits.

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

Data and methods

The analysed data set included the insemination records from all Finnish milk-recording herds during 2015. We were able to include thousands of herds in the analyses. The data also included the EBVs of most imported bulls, and the inseminations performed by all the companies operating in Finland. This very comprehensive data set makes our results reliable and representative, with no bias caused by participation interest, which is possible in survey-based preference studies, as discussed by Martin-Collado et al. (2015).

Farmers' realized selection preferences of AI bull' traits have not previously been studied using CA on this kind of data. However, insemination data have been used in constructing an aggregate breeding goal genotype assuming that decision maker preferences can be expressed with the predicted breeding values of animals (Alfonso, 2016).

CA has been used for stated preferences of AI bull selection with the option of an analysis generated number of clusters, for example by Martin-Collado et al. (2015). The number of clusters in this method is pre-selected. Given the large number of traits in our data, we hypothesized that within-herd selection could be differentiated by the main trait classes such as production, health, fertility, conformation and longevity traits. We ran the CA by varying the number of clusters from two to five. Using two clusters separated the Conformation herds from the rest but gave no information on a favoured trait in the remaining very large herd group. We decided to use four clusters in the analysis to explore the remaining variation in the heterogeneous non-Conformation group. Using four clusters captured herd groups coinciding with the main trait classes: yield, fertility, health, and conformation. The difference between Conformation herds and the rest remained in our final result with four herd groups. Running the CA with five clusters formed herd groups with only a few traits showing statistically significant differences.

AI bull selection in different herd groups

371 We observed differences in farmers' AI bull selection profiles between the herd
372 groups. The Conformation herd group was the most distinctive group in both breeds.
373 The rest of the herd groups had fairly similar bull selection profiles with some
374 deviations: All-rounder herds selected bulls evenly selecting for several traits,
375 whereas Production herds focused the selection on production-related traits and
376 Fertility herds on fertility and calving traits. In Conformation herds farmers focused on
377 improving frame and udder conformation with little attention to other traits.
378 Concentrating only on conformation traits may stem from these farmers being
379 content with the level of other traits in their herds. For example the average
380 phenotypic yield of HOL cows and heifers was the highest in the Conformation group.
381 The reason for the narrowly focused selection profile of Conformation herds may also
382 be based on a view that conformation traits are good indicators of longevity. A
383 conformation-related group was also seen when we analysed the diversity of
384 available AI bulls using trait EBVs as variables in the CA (results not shown here).

385 AI bull usage in the mixed-breed herds was very similar to pure herds. This implies
386 that AI bull selection is very similar regardless of the breed or breed proportions of
387 the herd. The only difference between pure and mixed herds was observed in AY,
388 where mixed herds was formed two groups, with one group highly emphasizing
389 conformation traits, while the other group focused not only on conformation traits but
390 also on other traits.

391 *Comparison of AI bull selection with the NTM-based selection*

392 In the Production, Fertility, and All-rounder herd groups the herd's bull selection
393 profiles deviated only slightly from the NTM selection, i.e. most farmers chose AI
394 bulls that fit the Nordic breeding goal quite well even if there were diverse AI bulls
395 available on the market. AI bull selection in the Conformation herd groups deviated
396 highly from the NTM selection, and was more extreme in AY. Nielsen et al. (2005)
397 discussed farmers' willingness to sacrifice genetic progress in production traits to
398 improve functional traits related to sustainability. Our results show how farmers are
399 willing to make compromises, such as concentrating only on conformation traits, and

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

this resulted in negative changes in the other economically more important traits such as yield and longevity. Herds' average NTM for cows was lowest in the Conformation herd groups in both breeds. This indicates that these farmers have also previously used AI bulls with low NTMs.

Within-herd deviations from NTM-based AI bull selection may slow down genetic progress in the traits that are given less attention than in NTM, or accelerate it in the traits that are emphasized more than in NTM. The NTM weights are close to optimum in an average herd in the Nordic production environment, while individual herds may benefit from tailoring the breeding objective to suit their specific conditions. Our results show that the proportion of herds deviating greatly from the NTM-guided selection is very low, and thereby should have minimal effect on the genetic progress at the population level. Hence, the overall genetic progress in Finnish dairy herds is well in line with the targeted selection defined by NTM.

The NTM is widely used and known among Finnish dairy farmers and our results therefore represent a valid comparison for herds' bull selection profiles in different herd groups. A higher selection differential in certain traits, and therefore a better economic impact compared to NTM-based selection was achieved in some herd groups. This can be explained by availability of bulls with higher EBVs, hence with higher selection differentials, in certain traits than what is calculated for the NTM based selection assuming an evenly distributed use of bulls above the truncation point.

Herd characteristics

Group averages for the herd characteristics give insight of the farms with differing AI bull selection preferences even though the within-group variation in herd characteristics was rather large in both breeds (Table S3; Table S6).

In Conformation herds, the apparent incongruence in trait preferences between conformation and other traits may be caused by these herds in both breeds averaging larger in size than in the other herd groups, and also because on average

farmers in these groups have invested in new loose-housing systems with milking robots and total mixed ration feeding in recent years. Conformation traits are, in general, valued higher in automatic milking and loose-housing than in traditional tie-stall barns. The scale and technological advantages in the Conformation herds may have enabled higher milk production even though the genetic level for yield is probably lower in these herds because of the AI bulls used.

All-rounder AY herds had the highest average yield per cow. Other yield characteristics were also fairly high, while calving interval was lower than in the other groups. This was reflected in the breeding choices: these farmers emphasized yield and fertility traits less than Production and Fertility herd farmers, possibly because of their smaller need to improve the herds' genetic level in these traits. For example, a high phenotypic yield may explain moving a herd's breeding objective away from the yield.

Future

Our results show that AI bull selection on large, advanced and well-managed farms differs from the Nordic breeding goal. In Finland, average herd size is predicted to increase from 37 in 2016 to 70 cows within five years (Kallinen et al., 2016). Natural Resources Institute Finland (Luke, 2017) estimates the number of dairy herds to decrease from the current 7 600 down to 4 900 by 2022. These predictions imply that AI bull selection made on dairy farms may begin deviating away from the Nordic breeding goal if large farms continue to follow the trends observed in our study. However, the overall future genetic level of Nordic AI bulls will depend on the NTM selection controlled by the breeding organizations in these countries.

Alternative TMIs provide farmers the opportunity for making selection choices based on their own preferences, while concurrently still following the population breeding objective at large. The population-level breeding goal and TMI need to be in line with farmer preferences to ensure farmer motivation in following the breeding goals and utilizing the TMI in their selection decisions. In recent years farmer preferences and opinions have been taken broadly into consideration when defining breeding

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

programmes. For example, three new TMIs have been developed in Australia (Byrne et al., 2016), each of which guide the genetic progress in the same direction with minor differences in the trait weighting.

According to our results, NTM is well accepted by most farmers, but fine-tuning the weights could be beneficial to better fit farmers' needs. This would improve the acceptance and utilization of NTM. Another option could be to develop alternative TMIs that all direct the genetic progress in the same direction, but have slightly different weightings to better fit farmer preferences. Alternative TMIs could help farmers in the first three herd groups to choose AI bulls. However, this is not enough to fulfil the Conformation herd farmers' needs. Our results show that conformation traits were emphasised more in herds with automatic milking systems, indicating a potential need for an index customised for such herds with more weight placed on conformation and other traits important for automatic milking, such as milkability. Development of a herd-specific TMI would fulfil the needs of very diverse herds, even the Conformation herds.

To investigate the relationship between stated farmers' preferences and realized selection of AI bulls we will design and conduct a follow-up survey-based study on Finnish dairy farmers' preferences concerning farm-level AI bull selection. The results of our future survey will be compared with results of our current analysis on the realized utilization of AI bulls. The study will explore whether farmers actually make AI bull selections based on their stated preferences and whether the Nordic breeding goal matches with farmer preferences. Information on a herd's realized AI bull selection could be used together with stated preferences to build a herd-specific TMI to include both conscious and subconscious criteria of AI bull selection.

Conclusions

Our results showed heterogeneity in Finnish dairy farmers' AI bull selection, and herds were clustered into distinct groups based on realized preferences. A majority of

farmers follow the Nordic breeding goal closely in their AI bull selection, but selection differs considerably from the Nordic breeding goal among large, advanced and well-managed herds. We observed a link between emphasizing conformation traits in herds' AI bull selection and a herd having an automatic milking system. Also, high yielding herds tended to select bulls with low EBVs for yield. Fine-tuning the NTM weights, and developing alternative TMIs or even herd-specific TMIs could provide better selection tools and improve the utilization of coordinated breeding programmes in herds with diverse AI bull selection profiles.

Acknowledgements

The authors would like to thank Faba co-op (Hollola, Finland), NAV (Aarhus, Denmark), and ProAgria (Vantaa, Finland) for providing the data used in the analyses. This work was undertaken with financial support from Faba co-op (Hollola, Finland) and VikingGenetics (Randers, Denmark). The comments of the Subject Editor and Referee are very much appreciated.

Conflict of interest statement

Paakala has worked as a Development Agronomist for the Faba co-op since October 2011.

References

Ahlstedt, J., Jansik, C., Knuuttila, M., Koikkalainen, K., Koivisto, A., Latukka, A., Liesivaara, P., Miettinen, A., Niemi, J., Pyysiäinen, J., Rantala, O., Rantamäki-Lahtinen, L., Sulkava, M., Tauriainen, J., Toikkanen, H., Väre, M., Wuori, O.

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

(2016, November 12). Finnish agriculture and rural industries 2015. Retrieved from <http://jukuri.luke.fi/handle/10024/519301>.

Alfonso, L. (2016). Technical note: An approach to derive breeding goals from the preferences of decision makers. *Journal of Dairy Science*. 94, 4498-4506. doi: 10.2527/jas.2016-0685.

Animal Health ETT. (2016, November 14). Naudan sperman tuonti 1995 - 2014. Retrieved from <https://www.ett.fi/sisalto/naudan-sperman-tuonti-1995-2014>.

Beliakov, G., Sola, H.B., Sánchez, T.C. (2016). *A Practical Guide to Averaging Functions*. Berlin, New York: Springer.

Byrne, T. J., Santos, B. F. S., Amer, P. R., Martin-Collado, D., Pryce, J. E. & Axford, M. (2016). New breeding objectives and selection indices for the Australian dairy industry. *Journal of Dairy Science*. 99, 8146-8167. doi:10.3168/jds.2015-10747.

Carlén, E., Pedersen, J., Pösö, J., Eriksson, J., Nielsen, U. S., & Aamand, G. P. (2016). Youngstock survival in Nordic cattle genetic evaluation. *Interbull Bulletin* 50:80-84.

Ghatak, A. (2017). *Machine Learning with R*. Singapore: Springer Nature.

ICAR. (2017, January 4). Milk recording surveys on cow, sheep and goats. Retrieved from <http://www.icar.org/survey/pages/tables.php>.

Kallinen, A., Pirttijärvi R., Saarnivaara, P., & Heikkilä, E. (2016, October 9). Maatilojen kehitysnäkymät 2022. Retrieved from <http://docplayer.fi/37602439-Maatilojen-kehitysnakymat-2022.html>

Kargo, M., Hjorto, L., Toivonen, M., Eriksson, J. A., Aamand, G. P., & J. Pedersen, J. (2014). Economic basis for the Nordic total merit index. *Journal of Dairy Science*. 97, 7879-7888. doi:10.3168/jds.2013-7694.

- 535 Luke. (2017, October 27). Luonnonvarakeskus. Taloustohtori. Maatalouden
536 rakennekehityssennuste. Retrieved from
537 [https://portal.mtt.fi/portal/page/portal/taloustohtori/rakennekehityssennuste/aikasar](https://portal.mtt.fi/portal/page/portal/taloustohtori/rakennekehityssennuste/aikasarja/tuotantosuunnat)
538 [ja/tuotantosuunnat](https://portal.mtt.fi/portal/page/portal/taloustohtori/rakennekehityssennuste/aikasarja/tuotantosuunnat).
- 539 MacQueen, J. (1967). Some methods for classification and analysis of multivariate
540 observations. Page 281-297 in Proc. Fifth Berkeley Symp. on Math. Statist. and
541 Prob. University of California Press.
- 542 Martin-Collado, D., Byrne, T. J., Amer, P. R., Santos, B. F. S., Axford, M., & Pryce, J.
543 E. (2015). Analyzing the heterogeneity of farmers' preferences for improvements
544 in dairy cow traits using farmer typologies. *Journal of Dairy Science*. 98, 4148-
545 4161. doi:10.3168/jds.2014-9194.
- 546 Morwitz, V. (2014). Consumers' purchase intentions and their behavior. *Foundations*
547 *and Trends® in Marketing*. 7, 181-230. doi:10.1561/17000000036.
- 548 Nielsen, H. M., Amer, P. R. & Byrne, T. J. (2014). Approaches to formulating practical
549 breeding objectives for animal production systems. *Acta Agriculturae*
550 *Scandinavica, Section A - Animal Science*. 64, 2-12.
551 doi:10.1080/09064702.2013.827237.
- 552 Nielsen, H. M., & Amer, P. R. (2007). An approach to derive economic weights in
553 breeding objectives using partial profile choice experiments. *Animal*. 1, 1254-
554 1262. doi:10.1017/S1731107/000729.
- 555 Nielsen, H. M., Christensen, L. G. & Groen, A. F. (2005). Derivation of sustainable
556 breeding goals for dairy cattle using selection index theory. *Journal of Dairy*
557 *Science*. 88, 1882-1890. doi:10.3168/jds.S0022-0302(05)72864-2.
- 558 Nordic Cattle Genetic Evaluation. (2016, March 27). NTM - weight factors. Retrieved
559 from http://www.nordicebv.info/wp-content/uploads/2016/05/NTM-%E2%80%93-weight-factors_02052016.pdf.

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60

561 Nordic Cattle Genetic Evaluation. (2016, December 5). NAV routine genetic
562 evaluation of dairy cattle - data and genetic models. Retrieved from
563 [http://www.nordicebv.info/wp-content/uploads/2015/04/General-description_from-](http://www.nordicebv.info/wp-content/uploads/2015/04/General-description_from-old-homepage_06052015.pdf)
564 [old-homepage_06052015.pdf](http://www.nordicebv.info/wp-content/uploads/2015/04/General-description_from-old-homepage_06052015.pdf).

565 R Core Team. (2016). R: A language and environment for statistical computing.
566 Vienna, Austria. Retrieved from <https://www.R-project.org>.

567 Slagboom, M., Kargo, M., Edwards, D., Sorensen, A. C., Thomasen, J. R., & Hjorto,
568 L. (2016). Organic dairy farmers put more emphasis on production traits than
569 conventional farmers. Journal of Dairy Science. 99, 9845-9856.
570 doi:10.3168/jds.2016-11346.

571 Tukey, J. (1949). Comparing individual means in the analysis of variance. Biometrics.
572 5, 99-114. doi:10.2307/3001913.

573 VikingGenetics. (2016a, November 16). About Holstein. Retrieved from
574 <http://www.vikinggenetics.com/breeds/vikingholstein>.

575 VikingGenetics. 2016b, November 16) About VikingRed. Retrieved from
576 <http://www.vikinggenetics.com/breeds/vikingred>.

577 vit IT-Solutions for Animal Production. (2016. November 22). Robot-index RZRobot.
578 Retrieved from [http://www.vit.de/index.php?id=milchrinder-zws-](http://www.vit.de/index.php?id=milchrinder-zws-online&no_cache=1&L=1)
579 [online&no_cache=1&L=1](http://www.vit.de/index.php?id=milchrinder-zws-online&no_cache=1&L=1).

580
581
582 **Supporting information**

583 **Table S1.** Averages and standard deviations of bull selection profiles and p-values
584 according to Tukey’s multiple comparison test between the AY herd groups.

Table S2. Averages and standard deviations of bull selection profiles and p-values according to Tukey's multiple comparison test between the mixed herd groups for AY bulls.

Table S3. Statistics of herd characteristics in all pure AY herds and in each of the four AY herd groups.

Table S4. Averages and standard deviations of bull selection profiles and p-values according to Tukey's multiple comparison test between the HOL herd groups.

Table S5. Averages and standard deviations of bull selection profiles and p-values according to Tukey's multiple comparison test between the mixed herd groups for HOL bulls.

Table S6. Statistics of herd characteristics in all pure HOL herds and in each of the four HOL herd groups.

Table 1 Traits in the Nordic Total Merit (NMT), their correlations with NTM (Nordic Cattle Genetic Evaluation, 2016) and the economic values (Carlén et al., 2016) for Ayrshire and Holstein AI bulls.

Trait or trait group	AY		HOL		Description
	Cor	EV	Cor	EV	
Yield	0.63	8.33	0.48	7.61	Milk, protein and fat yield.
Longevity ¹	0.49	0.61	0.61	1.12	Time from first calving to end of third lactation.
Feet & legs	0.33	0.78	0.19	1.22	Feet and leg conformation.
Udder health	0.27	2.78	0.42	3.55	Mastitis resistance.
Udder	0.26	2.78	0.14	2.54	Udder conformation.

Youngstock survival ²	0.26	2.03	0.27	1.40	Survival of heifer calves (1–458 d) and bull calves (1–30 d).
Birth index	0.25	1.21	0.35	1.52	Calf survival and calving ease, as a direct effect.
Fertility	0.22	2.26	0.43	3.15	Interval from first to last insemination, interval from calving to first insemination, and number of inseminations.
Calving index	0.22	1.04	0.30	1.72	Calf survival and calving ease, as a maternal effect.
Milkability	0.16	0.87	0.02	0.81	Herd owners' assessment or milk flow data from an automatic milking system.
Other diseases	0.15	1.04	0.45	1.12	Resistance for metabolic, feet and leg, and reproductive diseases.
Claw health ³	0.05	0.43	0.36	0.81	Includes claw health data recorded by claw trimmer.
Temperament	0.04	0.26	0.00	0.30	Herd owners' assessment
Growth ⁴	0.02	0.00	0.10	0.61	Carcass gain and carcass conformation score.
Frame	0.00	0.00	-0.10	0.00	Body conformation.

¹Included in NTM since 2010.

²Included in NTM since 2016.

³Included in NTM since 2011.

⁴Included in NTM since 2009.

Table 2 *Percentage of herds and inseminations in Ayrshire and Holstein herd groups.*

	AY		HOL	
	Herds (%)	Inseminations (%)	Herds (%)	Inseminations (%)
Yield herds	35.3	36.6	31.1	31
Fertility herds	30.7	29.2	51.5	47.2
All-rounder herds	29.5	32.1	8.8	12.4
Conformation herds	4.5	2.2	8.6	9.4

The expected genetic progress in NTM selection and mean of herd’s bull selection profiles in the four different herd groups in both AY and HOL breeds in yield, growth and milkability. EBVs in the Nordic countries are scaled to an average of 100. a–d, Averages with different superscripts within a trait and breed differ (at least with $P < 0.05$) according to Tukey’s multiple comparison test.

128x73mm (300 x 300 DPI)

The expected genetic progress in NTM selection and mean of herd’s bull selection profiles in the four different herd groups in both AY and HOL breeds in fertility and longevity. EBVs in the Nordic countries are scaled to an average of 100. a–d, Averages with different superscripts within a trait and breed differ (at least with $P < 0.05$) according to Tukey’s multiple comparison test.

170x99mm (300 x 300 DPI)

The expected genetic progress in NTM selection and mean of herd’s bull selection profiles in the four different herd groups in both AY and HOL breeds in frame, feet and leg an udder conformation. EBVs in the Nordic countries are scaled to an average of 100. a–d, Averages with different superscripts within a trait and breed differ (at least with $P < 0.05$) according to Tukey’s multiple comparison test.

170x99mm (300 x 300 DPI)

Table S1. Averages and standard deviations of bull selection profiles (an average of the utilized AI bulls' 14 EBVs over all the inseminations in the herd) in the AY herd groups and p-values according to Tukey's multiple comparison test between the herd groups in the 14 traits included in NTM.

	1 Pro- duc- tion	SD 1	2 Ferti- lity	SD 2	3 All- roun- ders	SD 3	4 Con- for- ma- tion	SD 4	p 1-2 ¹	p 1-3 ²	p 1-4 ³	p 2-3 ⁴	p 2-4 ⁵	p 3-4 ⁶
Yield	114.0	1.37	113.0	1.08	112.6	1.75	92.2	6.50	<0.001	<0.001	<0.001	0.01	<0.001	<0.001
Growth	99.5	1.13	97.8	1.40	98.1	1.81	84.0	5.02	<0.001	<0.001	<0.001	0.08	<0.001	<0.001
Udder health	105.9	1.22	107.3	1.35	107.5	1.62	102.9	3.05	<0.001	<0.001	<0.001	0.23	<0.001	<0.001
Other diseases	105.1	1.23	106.1	1.86	105.3	1.44	92.4	4.77	<0.001	0.10	<0.001	<0.001	<0.001	<0.001
Claw health	102.5	1.28	103.5	1.41	103.4	1.40	109.7	4.60	<0.001	<0.001	<0.001	0.20	<0.001	<0.001
Fertility	104.3	1.44	106.3	2.03	104.5	1.63	93.0	6.59	<0.001	0.18	<0.001	<0.001	<0.001	<0.001
Birth	104.3	1.43	105.4	1.46	103.1	1.49	93.8	4.39	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Calving	103.6	1.33	104.6	1.40	104.1	1.38	101.8	3.20	<0.001	<0.001	0.01	<0.001	<0.001	<0.001
Temperament	103.3	1.42	103.3	1.62	102.6	1.35	96.0	2.81	1.00	<0.001	<0.001	<0.001	<0.001	<0.001
Milkability	105.2	2.14	104.8	2.35	104.2	2.12	94.9	3.67	0.10	<0.001	<0.001	<0.001	<0.001	<0.001
Longevity	112.6	1.42	113.4	1.25	111.9	1.44	96.0	5.25	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Frame	102.2	1.39	101.1	1.50	103.6	1.48	108.3	2.41	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Feet & Legs	105.8	1.80	108.0	2.23	105.8	2.11	103.9	3.38	<0.001	1.00	<0.001	<0.001	<0.001	<0.001
Udder	108.0	1.71	108.8	1.99	112.0	1.98	116.3	4.20	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

¹ P-value between Production and Fertility herd groups.

² P-value between Production and All-rounders herd groups.

³ P-value between Production and Conformation herd groups.

⁴ P-value between Fertility and All-rounders herd groups.

⁵ P-value between Fertility and Conformation herd groups.

⁶ P-value between All-rounders and Conformation herd groups.

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47

Table S2. Averages and standard deviations of bull selection profiles (an average of the utilized AI bulls' 14 EBVs over all the inseminations in the herd) in the mixed herd groups for AY AI bulls and p-values according to Tukey's multiple comparison test between the herd groups in the 14 traits included in NTM.

	1		2		3		4							
	Pro-		Fer-		Con-		Con-		p 1-2 ¹	p 1-3 ²	p 1-4 ³	p 2-3 ⁴	p 2-4 ⁵	p 3-4 ⁶
	duc-	SD 1	tility	SD 2	for-	SD 3	for-	SD 4						
	tion				ma-		ma-							
					tion+		tion							
Yield	113.5	1.78	113.4	1.69	101.8	5.50	88.2	6.54	1.00	<0.001	<0.001	<0.001	<0.001	<0.001
Growth	99.0	2.18	98.7	1.84	92.1	4.57	82.1	6.34	0.18	<0.001	<0.001	<0.001	<0.001	<0.001
Udder health	106.7	1.63	106.7	1.86	104.9	2.68	101.1	3.44	1.00	<0.001	<0.001	<0.001	<0.001	<0.001
Other diseases	105.0	1.50	105.5	1.72	98.0	3.77	88.2	7.46	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Claw health	102.9	1.58	103.1	1.73	108.6	4.05	112.5	6.13	0.90	<0.001	<0.001	<0.001	<0.001	<0.001
Fertility	103.8	1.98	105.2	2.02	97.9	4.89	91.6	6.88	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Birth	102.6	1.62	105.0	1.53	99.0	3.97	96.6	5.38	<0.001	<0.001	<0.001	<0.001	<0.001	0.40
Calving	103.9	1.74	103.9	1.58	101.9	2.61	100.8	4.10	1.00	<0.001	<0.001	<0.001	<0.001	1.00
Temperament	103.4	1.67	102.9	1.93	98.7	5.60	97.5	7.57	<0.001	<0.001	<0.001	<0.001	<0.001	1.00
Milkability	106.2	2.56	104.3	2.65	98.0	4.01	93.3	2.06	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Longevity	112.3	1.74	112.8	1.96	104.1	4.05	91.7	5.70	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Frame	104.4	1.69	101.4	1.55	105.5	2.21	108.6	3.64	<0.001	0.02	<0.001	<0.001	<0.001	<0.001
Feet & Legs	105.3	2.17	107.1	2.44	105.5	4.61	106.7	5.40	<0.001	1.00	0.21	0.74	1.00	1.00
Udder	111.1	2.26	108.2	2.37	113.8	4.17	118.4	4.68	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

¹ P-value between Production and Fertility herd groups.

² P-value between Production and Conformation+ herd groups.

³ P-value between Conformation+ and Conformation herd groups.

⁴ P-value between Fertility and Conformation+ herd groups.

⁵ P-value between Fertility and Conformation herd groups.

⁶ P-value between Yield and Conformation and Conformation herd groups.

Table S3. Mean, standard deviation, minimum and maximum of herd characteristics in all pure AY herds and in each of the 4 AY herd groups.

Herds (n)	All herds 1279				1 Production herds 452				2 Fertility herds 393				3 All-rounder herds 377				4 Conformation herds 57			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
Herd size ¹	29.0	19.6	4.7	197.5	27.8 ^{ab}	18.4	6.3	173.8	24.8 ^a	13.9	4.7	128.0	30.7 ^b	19.5	4.7	160.7	53.5	34.6	14.9	197.5
ECM ²	9312	1426	662	12616	9053 ^a	1546	662	12616	9276 ^a	1355	1412	12610	9686	1248	1231	12458	9152 ^a	1524	2180	11165
Average yield, cows ³	8735	1289	699	12424	8459 ^b	1384	699	11789	8678 ^{ab}	1237	4017	12424	9095 ^c	1153	2374	12231	8909 ^{abc}	1174	4174	10974
Average yield, heifers ⁴	7723	1208	780	11522	7510 ^c	1278	780	10353	7724 ^a	1155	3634	11522	7987 ^b	1155	1466	10372	7658 ^{abc}	1040	4531	9412
Lifetime yield, live cows ⁵	19462	4805	6115	52174	18835 ^b	4893	6115	38683	19226 ^{ab}	4942	8293	52174	20221 ^c	4358	6659	37428	20844 ^{ac}	5086	12343	39053
Lifetime yield, culled cows ⁶	27051	6981	4377	76961	26641 ^a	7338	6383	76961	26955 ^a	6984	4835	75097	27548 ^a	6513	4377	54310	27592 ^a	7047	15904	54144
No of calvings ⁷	2.4	0.4	1.4	6.0	2.4 ^a	0.4	1.5	4.3	2.4 ^a	0.5	1.4	6.0	2.5 ^a	0.4	1.5	3.9	2.5 ^a	0.4	1.7	4.0
Calving age ⁸	26.3	2.4	18.9	54.2	26.4 ^a	2.5	18.9	39.5	26.3 ^a	2.5	22.6	54.2	26.0 ^a	2.1	20.8	41.2	26.5 ^a	1.8	23.0	31.9
Calving interval ⁹	418.3	35.7	349.0	706.0	421.0 ^a	37.3	349.0	616.0	420.8 ^a	39.6	355.0	706.0	411.8 ^b	29.0	354.0	575.0	422.0 ^{ab}	29.1	376.0	535.0
No of inseminations, cows ¹⁰	1.89	0.41	1.00	5.25	1.88 ^a	0.40	1.00	3.43	1.89 ^a	0.40	1.00	3.60	1.92 ^a	0.43	1.11	5.25	1.89 ^a	0.42	1.04	3.23
No of inseminations, heifers ¹¹	1.61	0.49	1.00	8.00	1.61 ^a	0.44	1.00	3.31	1.61 ^a	0.54	1.00	8.00	1.61 ^a	0.49	1.00	5.67	1.67 ^a	0.52	1.00	3.50
Culling %, cows ¹²	31.5	11.4	0.0	81.7	31.5 ^a	11.9	4.1	78.7	31.6 ^a	11.3	0.0	79.8	30.2 ^a	11.0	4.8	81.7	34.4 ^a	10.7	16.8	79.7
Culling %, heifers ¹³	18.7	17.1	0.0	96.8	19.1 ^a	17.3	0.0	96.8	18.8 ^a	18.0	0.0	82.2	17.5 ^a	15.4	0.0	83.3	23.2 ^a	18.0	0.0	87.7
Cow mortality ¹⁴	5.2	5.6	0.0	35.3	5.0 ^b	5.7	0.0	35.3	5.3 ^b	5.7	0.0	30.9	5.2 ^a	5.6	0.0	34.1	5.5 ^a	4.2	0.0	14.3
Stillborn calves ¹⁵	6.4	6.1	0.0	50.0	6.5 ^a	6.4	0.0	45.5	6.2 ^a	6.7	0.0	50.0	6.1 ^a	5.4	0.0	34.8	7.5 ^a	4.3	0.0	18.2
Animal density ¹⁶	0.56	0.25	0.11	2.53	0.57 ^a	0.25	0.11	1.88	0.55 ^a	0.25	0.14	2.53	0.54 ^a	0.22	0.14	1.31	0.71	0.41	0.14	2.17
Investment year ¹⁷	1997	14	1900	2015	1997 ^a	14	1900	2015	1996 ^a	15	1908	2015	1997 ^a	12	1939	2015	2006	8	1980	2014
NTM ¹⁸	-0.17	3.69	-17.90	12.60	-0.39 ^b	12.60	-11.20	10.20	0.18 ^{ab}	3.08	-12.50	7.70	0.80 ^a	3.33	-11.30	12.60	-6.33	5.04	-17.90	1.90
Housing type																				
Stanchion barn (%)	80.20				79.40 ^a				81.20 ^a				70.70 ^b				53.80 ^c			
Loose housing (%)	18.70				15.70 ^a				12.80 ^a				22.20 ^b				36.90 ^c			
Other (%)	1.10				0.70 ^a				1.10 ^a				1.40 ^b				3.30 ^c			
Feeding type																				
Separate feeding (%)	93.70				96.10 ^a				95.80 ^a				94.00 ^a				63.50 ^b			
Mixed ration (%)	6.30				3.90 ^a				4.20 ^a				6.00 ^a				36.50 ^b			
Milking machine																				
Automatic milking (%)	4.70				5.00 ^{ab}				2.10 ^a				4.10 ^b				22.60 ^c			
Milking parlors (%)	16.10				13.40 ^{ab}				12.50 ^a				22.10 ^b				22.60 ^c			
Pipeline milking (%)	77.30				79.60 ^{ab}				82.00 ^a				73.30 ^b				54.80 ^c			
Bucket milking (%)	1.90				2.00 ^{ab}				3.40 ^a				0.50 ^b				0.00 ^c			
Production type																				
Conventional (%)	98.30				97.80 ^a				98.50 ^a				98.70 ^a				98.50 ^a			
Organic (%)	1.70				2.20 ^a				1.50 ^a				1.30 ^a				1.50 ^a			
Subsidy area																				
South (%)	25.30				23.10 ^a				23.60 ^a				28.40 ^a				33.80 ^a			
North (%)	74.70				76.90 ^a				76.40 ^a				71.60 ^a				66.20 ^a			

¹Number of cows in herd²Energy corrected milk yield (kg) per cow³Milk yield (kg) per cow⁴Milk yield (kg) per heifer⁵Lifetime milk yield (kg) per cow, live cows⁶Lifetime milk yield (kg) per cow, culled cows⁷Average number of calvings per cow⁸Heifers calving age (months)⁹Calving interval (days)¹⁰No of inseminations per calving, cows¹¹No of inseminations per calving, heifers¹²Percentage of planned cullings, cows¹³Percentage of planned cullings, heifers¹⁴Percentage of cows that die or need culling on the farm¹⁵Percentage of calves that are stillborn or die within 7 days¹⁶Number of cows / ha¹⁷Year of latest investment on the farm

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47

¹⁸Average total merit index of herds cows, all breeds

For Peer Review

Table S4. Averages and standard deviations of bull selection profiles (an average of the utilized AI bulls' 14 EBVs over all the inseminations in the herd) in the HOL herd groups and p-values according to Tukey's multiple comparison test between the herd groups in the 14 traits included in NTM.

	1 Pro- duc- tion	SD 1	2 Ferti- lity	SD 2	3 All- roun- ders	SD 3	4 Con- for- ma- tion	SD 4	p 1-2 ¹	p 1-3 ²	p 1-4 ³	p 2-3 ⁴	p 2-4 ⁵	p 3-4 ⁶
Yield	115.8	1.78	113.7	1.81	113.0	2.98	107.9	3.41	<0.001	<0.001	<0.001	0.88	<0.001	<0.001
Growth	101.1	2.20	98.6	1.78	96.2	3.63	92.3	4.58	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Udder health	109.6	1.62	111.3	1.46	106.4	2.61	99.7	3.18	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Other diseases	107.2	1.20	107.7	1.21	103.8	2.60	96.9	3.32	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Claw health	107.6	1.20	108.0	1.65	105.8	2.41	99.8	2.93	0.02	<0.001	<0.001	<0.001	<0.001	<0.001
Fertility	109.0	2.27	111.1	2.00	106.7	3.30	95.4	5.26	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Birth	104.8	1.54	104.7	1.45	101.8	2.54	97.3	2.83	1.00	<0.001	<0.001	<0.001	<0.001	<0.001
Calving	107.7	1.27	108.4	1.15	107.2	3.40	102.3	3.96	<0.001	1.00	<0.001	0.13	<0.001	<0.001
Temperament	104.1	1.88	103.1	1.59	105.2	3.00	107.1	3.20	<0.001	0.10	<0.001	<0.001	<0.001	0.04
Milkability	102.4	2.48	99.8	1.77	104.1	4.11	100.1	3.92	<0.001	0.08	<0.001	<0.001	1.00	<0.001
Longevity	118.4	1.41	119.2	1.74	115.0	2.73	104.7	3.28	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Frame	103.8	2.65	105.6	2.28	111.7	3.90	121.2	3.37	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Feet & Legs	105.3	1.72	106.2	1.74	106.3	2.60	104.9	2.33	<0.001	0.11	1.00	1.00	0.01	0.05
Udder	113.1	1.77	114.6	1.65	116.1	3.29	117.1	3.07	<0.001	<0.001	<0.001	0.02	<0.001	0.74

¹ P-value between Production and Fertility herd groups.

² P-value between Production and All-rounders herd groups.

³ P-value between Production and Conformation herd groups.

⁴ P-value between Fertility and All-rounders herd groups.

⁵ P-value between Fertility and Conformation herd groups.

⁶ P-value between All-rounders and Conformation herd groups.

Table S5. Averages and standard deviations of bull selection profiles (an average of the utilized AI bulls' 14 EBVs over all the inseminations in the herd) in the mixed herd groups for HOL AI bulls and p-values according to Tukey's multiple comparison test between the herd groups in the 14 traits included in NTM.

	1 Pro- duc- tion	SD 1	2 Fer- tility	SD 2	3 All- roun- ders	SD 3	4 Con- for- ma- tion	SD 4	p 1-2 ¹	p 1-3 ²	p 1-4 ³	p 2-3 ⁴	p 2-4 ⁵	p 3-4 ⁶
Yield	115.5	2.53	113.7	1.87	110.2	3.51	106.4	2.61	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Growth	100.9	2.67	98.6	2.26	96.5	4.73	90.6	3.87	<0.001	<0.001	<0.001	0.02	<0.001	<0.001
Udder health	109.0	2.22	111.4	1.73	103.2	3.08	98.1	3.47	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Other diseases	106.8	1.53	107.7	1.49	101.6	2.32	95.1	3.16	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Claw health	107.5	1.74	108.2	1.85	103.0	3.35	97.8	4.70	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Fertility	108.3	2.80	111.2	2.14	103.0	4.05	92.8	4.64	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Birth	104.3	1.79	104.7	1.64	101.4	2.90	96.7	2.81	0.02	<0.001	<0.001	<0.001	<0.001	<0.001
Calving	107.6	1.66	108.2	1.34	106.2	2.95	102.1	4.88	<0.001	0.01	<0.001	<0.001	<0.001	<0.001
Temperament	104.4	2.45	103.0	1.88	105.6	3.64	108.6	3.50	<0.001	0.12	<0.001	<0.001	<0.001	<0.001
Milkability	102.8	2.85	99.6	2.13	103.2	4.62	99.8	4.27	<0.001	1.00	<0.001	<0.001	1.00	<0.001
Longevity	117.9	1.75	119.2	1.88	110.2	3.30	102.7	4.01	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Frame	104.9	3.24	105.3	2.65	115.2	4.00	122.7	3.37	0.40	<0.001	<0.001	<0.001	<0.001	<0.001
Feet & Legs	105.5	1.89	106.0	1.98	104.4	2.78	104.9	1.71	0.01	0.06	0.02	<0.001	<0.001	1.00
Udder	113.3	2.65	114.5	2.01	115.9	4.07	115.9	3.57	<0.001	<0.001	<0.001	0.17	0.01	1.00

¹ P-value between Production and Fertility herd groups.

² P-value between Production and All-rounders herd groups.

³ P-value between Production and Conformation herd groups.

⁴ P-value between Fertility and All-rounders herd groups.

⁵ P-value between Fertility and Conformation herd groups.

⁶ P-value between All-rounders and Conformation herd groups.

Table S6. Mean, standard deviation, minimum and maximum of herd characteristics in all pure HOL herds and in each of the 4 HOL herd groups.

Herds (n)	All herds 544				1 Production herds 169				2 Fertility herds 280				3 All-rounder herds 48				4 Conformation herds 47			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
Herd size ¹	36.9	30.0	3.8	273.6	33.3 ^a	23.0	4.4	162.0	28.6 ^a	19.5	5.8	224.8	64.1 ^b	49.6	3.8	273.6	71.1 ^b	36.9	16.2	201.6
ECM ²	9964	1367	2862	12979	10054 ^a	1289	5556	12896	9820 ^a	1323	5125	12979	10158 ^a	1428	6271	12474	10292 ^a	1724	2862	12298
Average yield, cows ³	9796	1312	5105	13049	9853 ^{ab}	1307	5105	12966	9580 ^a	1281	5194	12761	10141 ^{bc}	1375	6443	13049	10529 ^c	1100	7087	12713
Average yield, heifers ⁴	8468	1284	3224	12151	8463 ^{ab}	1299	3955	11565	8299 ^a	1287	3224	12151	8811 ^{bc}	1141	6251	10979	9135 ^c	1090	6213	11445
Lifetime yield, live cows ⁵	21384	5292	8077	39714	21519 ^a	4962	11370	39424	21238 ^a	5667	8077	39714	20297 ^a	3881	8874	31068	22882 ^a	5185	9492	33919
Lifetime yield, culled cows ⁶	29772	8085	4166	74272	29412 ^{abc}	7478	9372	59231	30526 ^{ad}	8710	4166	74272	26819 ^{ae}	6663	13131	54142	29592 ^{bde}	7027	13195	48586
No of calvings ⁷	2.4	0.4	1.3	4.5	2.4 ^a	0.4	1.5	3.9	2.5 ^a	0.5	1.3	4.5	2.3 ^a	0.4	1.5	3.8	2.4 ^a	0.4	1.7	3.1
Calving age ⁸	26.3	2.3	21.4	44.9	26.2 ^a	2.4	21.4	39.7	26.5 ^a	2.5	22.5	44.9	26.1 ^a	1.7	22.9	30.6	25.8 ^a	1.6	23.4	31.1
Calving interval ⁹	418.0	30.6	353.0	637.0	415.2 ^a	29.2	371.0	552.0	419.5 ^a	33.4	353.0	637.0	417.5 ^a	22.7	380.0	498.0	420.0 ^a	24.9	379.0	490.0
No of inseminations, cows ¹⁰	1.79	0.36	1.00	3.50	1.82 ^a	0.38	1.00	3.50	1.77 ^a	0.36	1.00	3.11	1.81 ^a	0.35	1.13	2.83	1.80 ^a	0.34	1.31	2.68
No of inseminations, heifers ¹¹	1.52	0.46	1.00	6.00	1.55 ^a	0.54	1.00	6.00	1.47 ^a	0.41	1.00	3.50	1.56 ^a	0.46	1.00	3.00	1.62 ^a	0.47	1.00	3.33
Culling %, cows ¹²	31.9	10.6	1.8	82.2	32.3 ^a	10.3	1.8	55.8	31.7 ^a	10.9	11.4	82.2	32.2 ^a	10.0	7.9	57.4	30.9 ^a	10.7	5.8	65.3
Culling %, heifers ¹³	17.3	15.4	0.0	98.0	18.9 ^a	16.7	0.0	98.0	16.0 ^a	15.0	0.0	76.9	19.6 ^a	15.1	0.0	73.2	17.1 ^a	11.8	0.0	48.1
Cow mortality ¹⁴	5.9	5.2	0.0	29.9	6.0 ^{abc}	4.9	0.0	24.1	5.5 ^{ad}	5.4	0.0	29.9	6.1 ^{cde}	4.1	0.0	20.7	7.9 ^{de}	5.3	0.0	29.1
Stillborn calves ¹⁵	6.4	6.4	0.0	65.2	7.0 ^a	8.1	0.0	65.2	5.7 ^a	5.5	0.0	25.0	6.6 ^a	5.3	0.0	21.8	8.3 ^a	4.3	0.0	19.7
Animal density ¹⁶	0.60	0.28	0.02	2.45	0.59 ^a	0.23	0.02	1.82	0.56 ^a	0.24	0.10	2.05	0.75 ^b	0.41	0.27	2.45	0.80 ^b	0.40	0.18	2.06
Investment year ¹⁷	1999	12	1930	2014	1998 ^a	13	1930	2014	1997 ^a	12	1950	2014	2005 ^b	7	1988	2014	2008 ^b	5	1991	2014
NTM ¹⁸	-0.71	3.34	-14.50	11.50	0.26 ^a	3.03	-11.30	8.80	-0.85 ^b	3.42	-14.50	11.50	-0.68 ^{ab}	3.06	-8.40	7.40	-3.32	2.65	-8.40	2.20
Housing type																				
Stanchion barn (%)	69.1				68.00 ^a				75.00 ^a				45.80 ^b				27.70 ^b			
Loose housing (%)	29.9				26.00 ^a				22.10 ^a				52.10 ^b				63.80 ^b			
Other (%)	1.0				1.30 ^a				0.40 ^a				2.10 ^b				2.30 ^b			
Feeding type																				
Separate feeding (%)	88.6				91.40 ^a				95.90 ^a				63.80 ^b				60.90 ^b			
Mixed ration (%)	11.4				8.60 ^a				4.10 ^a				36.20 ^b				39.10 ^b			
Milking machine																				
Automatic milking (%)	16.9				17.00 ^a				4.70 ^a				47.90 ^b				55.30 ^b			
Milking parlors (%)	15.7				12.10 ^a				18.20 ^a				8.30 ^b				21.30 ^b			
Pipeline milking (%)	65.9				68.50 ^a				76.30 ^a				39.60 ^b				23.40 ^b			
Bucket milking (%)	1.5				2.40 ^a				0.70 ^a				4.20 ^b				0.00 ^b			
Production type																				
Conventional (%)	98.9				100.00 ^a				98.60 ^a				97.90 ^a				97.90 ^a			
Organic (%)	1.1				0.00 ^a				1.40 ^a				2.10 ^a				2.10 ^a			
Subsidy area																				
South (%)	15.1				17.80 ^a				13.20 ^a				14.90 ^a				17.00 ^a			
North (%)	84.9				82.20 ^a				86.80 ^a				85.10 ^a				83.00 ^a			

¹Number of cows in herd²Energy corrected milk yield (kg) per cow³Milk yield (kg) per cow⁴Milk yield (kg) per heifer⁵Lifetime milk yield (kg) per cow, live cows⁶Lifetime milk yield (kg) per cow, culled cows⁷Average number of calvings per cow⁸Heifers calving age (months)⁹Calving interval (days)¹⁰No of inseminations per calving, cows¹¹No of inseminations per calving, heifers¹²Percentage of planned cullings, cows¹³Percentage of planned cullings, heifers¹⁴Percentage of cows that die or need culling on the farm¹⁵Percentage of calves that are stillborn or die within 7 days¹⁶Number of cows / ha¹⁷Year of latest investment on the farm

1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
46
47

¹⁸Average total merit index of herds cows, all breeds

For Peer Review