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Animal Welfare 2011, 20: 145-158
ISSN 0962-7286

The effect of management system on mortality and other welfare indicators in Pennsylvania dairy herds

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Abstract

*The objective of this study was to identify farm characteristics that were associated with cow (*Bos taurus*) welfare outcomes, including mortality rate, culling by 60 days of lactation, survival to ≥ 6 years of age and ≥ 5th parity (aged cows), somatic cell score, milk yield, and milk composition. Data were collected on housing systems, feeding systems, pasture strategies, bedding type, labour management practices and other farm characteristics in face-to-face interviews with 314 Pennsylvania dairy herd owners where performance records were available. Five herd management systems were identified in the sample: free-stalls with complete confinement (n = 37); free-stalls that allowed outdoor access (n = 76); tie-stalls with complete confinement (n = 52); tie-stalls with outdoor access and that fed a total mixed ration (n = 72); and tie-stalls with outdoor access and that did not feed a total mixed ration (n = 77). Welfare outcomes were evaluated with multivariable linear regression models and marginal means were estimated for herd management system. Tie-stalls that allowed outdoor access and that did not feed total mixed rations had the lowest mortality rate (2.0%), culling in the first 60 days of lactation (5.1%), and the highest proportion of aged cows (13.8%). Those herds also had high lifetime-to-date milk yield, a low proportion of fat-protein inversions, and low somatic cell scores. Free-stalls with complete confinement had significantly higher levels of mortality (8.3%), culling in the first 60 days of lactation (9.7%), and fewer aged cows (6.4%). It was concluded that shifts toward more efficient herd management systems have not benefited cow health and welfare. This suggests that cow welfare has been compromised to facilitate the economic survival of dairy farms.*

Keywords: *animal welfare, culling, dairy cattle, housing, management, mortality*

Introduction

Social concern for the treatment of farm animals has resulted in legislative efforts intended to improve their well-being in the USA (California 2008). Many food industry groups have also developed best management practices intended to provide uniform standards of animal care and demonstrate a commitment to animal welfare. For example, the National Dairy Animal Well-Being Initiative (NDAWBI 2009) was launched by the dairy industry. The identification of animal management practices and production systems that enhance dairy cow (*Bos taurus*) welfare will help facilitate the development of legislative and industry efforts that will accomplish their intended aim.

Economic pressure has dictated that dairy farms become more efficient. The proportion of the retail food dollar that is returned to dairy producers declined from approximately 50% in 1980 to 30% in 2000 (ERS-USDA 2009). Not surprisingly, trends in cow health and survival during this timeframe were not favourable. Holstein cows born in 2000 remained in the milking herd 3.95 months fewer than those born in 1980 (AIPL-USDA 2009) and on-farm cow mortality rates were estimated to rise from 3.8% in 1996, to 4.8% in 2002 and 5.7% in 2007 (NAHMS II 2007). Mortality risk for Danish dairy cows was also reported to increase from 2 to 3.5% from 1990 to 1999 (Thomsen *et al* 2004). On-farm mortality rates rose before restrictions limiting the sale of downer cows were enacted in the US (Miller *et al* 2008), which indicates rising mortality is due to degraded cow health rather than legislative changes. Mortality rates have risen even though the mean age of cows has declined steadily (Hare *et al* 2006). The most recent trends for cow lifespan have improved slightly (AIPL-USDA 2009). This likely reflects aggressive use of reproductive synchronisation programmes (Caraviello *et al* 2006; Miller *et al* 2007) and a subsequent reduction in culling for reproductive failure. Genetic selection for milk yield is reported to be unfavourably correlated with mastitis (Zwald *et al* 2004; Negussie *et al* 2008; Vallimont *et al* 2009) and diseases other than mastitis (Rogers *et al* 1999; Zwald *et al* 2004). There are also breed differences in mortality rates. An analysis of > 2 million records revealed that the Holstein breed has higher mortality rates than other common dairy breeds in the USA (Miller *et al* 2008), whereas an analysis of > 7 million records revealed a higher mortality rate in Danish Jerseys than for Danish Holsteins (Thomsen *et al* 2004). Unfavourable genetic correlation estimates between yield and diseases are generally modest, but continued selection for yield can have a large and unfavourable effect on cow health over time (Shook 1989); nevertheless, heritability estimates for disease are low and the genetic trend for herd life has actually increased by 3.39 months from 1980 to 2000 (AIPL-USDA 2009). This suggests that decline in survival is due to shifts in herd management more than genetic selection, or that management systems have not improved to accommodate cows with higher genetic merit for milk yield.

Dairy farm numbers in the USA decreased from 180,640 in 1991 to 75,140 in 2006 (NAHMS II 2007). A majority of cows (54.6%) resided in herds with 100 cows or fewer in 1991 compared with 24.2% in 2006. Shifts in herd size are associated with changes to herd management that could alter cow behaviour and survival. The proportion of cows milked in tie-stalls declined from 43.9% in 1996 to 21.8% in 2007 (NAHMS II 2007). Herds with < 100 cows are more likely to utilise pasture (64.3%) than herds with ≥ 500 cows (16.1%) and the proportion of herds feeding a total mixed ration (TMR) was reported to be 94.1% for herds with ≥ 500 cows versus 37.8% for herds with < 100 cows (NAHMS I 2007). Less outdoor access for lactating cows, feeding TMR, and shifts away from tie-stall housing systems have all been associated with higher mortality (McConnel *et al* 2008). Smaller farms may also give individual cows more attention than larger and more labour-efficient farms. Providing cows with individual attention, including identifying cows by name and brushing heifers before calving, has positive impacts on cow behaviour and performance (Bertenshaw *et al* 2008, 2009).

Winckler *et al* (2003) described mortality rate as an indicator of cow welfare, but noted that recording may be inaccurate for some farms and that the frequency may be too low to be a dependable measure of welfare in some instances. Nevertheless, mortality rate exceeded 5% across Pennsylvania dairy farms and was highly correlated with culling in early lactation (Dechow & Goodling 2008). Herds with high mortality also had significantly higher somatic cell scores, had significantly higher milk yield from young cows and significantly lower milk yields from mature cows, had higher milk-fat percent in early lactation, a more rapid decline in milk-fat percent after calving, and a higher proportion of fat-protein inversions. The objectives of this study were to determine what impact various herd management systems (HMS) had on cow welfare, as indicated by mortality, culling, survival to six years of age and fifth parity, and other measures of cow productivity.

Materials and methods

Questionnaires were provided to Dairy Herd Information (DHI) technicians during the summers of 2006 and 2007. Forms were completed during the technicians' normal routine on the farm. This involved the technician asking questions of farmers while they milked. Alternatively, the questionnaire could be filled out by the farm manager in the presence of the DHI technician. Completed forms were received from 392 Pennsylvania dairy farms. Herds enrolled in a DHI programme are generally visited once per month by a technician that weighs the milk produced by each cow, collects milk samples to be analysed for milk composition, records breeding dates, calving dates, cows that have entered or exited the herd, and parent identification. Not all herds enroll in monthly DHI programmes, and may have bi-monthly or irregular DHI test intervals. Some may only participate on an as-needed basis in order to identify cows contributing to a high herd somatic cell count or other short-term management problem. Some herds may also forego testing during inconvenient seasons of the year (harvesting, planting, pasturing). Such herds are likely to provide inaccurate information because details like culling dates are more likely to be forgotten in long intervals between tests or the herd is interested in one specific aspect of information (detecting sub-clinical mastitis, for example) and not features such as herd inventory. Records from 78 herds that returned questionnaires but that were not on a regular testing schedule (longer than every other-month DHI test intervals) or that were not on test for all of 2005 were eliminated, leaving 314 herds for analysis.

The questionnaire was constructed to fit on a single two-sided page and was provided to DHI personnel before the trial to provide an opportunity for technicians to suggest improvements and to become familiar with the forms. This data collection method provided some measure of oversight because DHI technicians were familiar with each herd and could verify the accuracy of most responses. Initially, 267 herds (221 with usable DHI data) were questioned by technicians from Lancaster DHI Association (Lancaster, PA, USA) in 2006. Those herds were not pre-selected by researchers and technicians were given no instructions about the type of herds to question. Lancaster DHI Association is located in the southeast portion of Pennsylvania and the largest portion of their service is provided in this region, but they also service the eastern, central, and northwest portions of the state. A second round was conducted by technicians from Dairy One (Ithaca, NY, USA) in 2007 to expand the number of herds included in the analysis. Dairy One services all of Pennsylvania and overlaps with all of Lancaster DHI Association's service area. Again, herds were not known or pre-selected; however, one goal of the project was to determine the impact of sand bedding and the use of rubberised walking surfaces. Only 10 herds used rubberised walkways and only four used sand bedding in the initial round, so technicians from Dairy One were instructed to specifically target such herds in the initial stages of their data collection period. Of the 93 questionnaires returned by Dairy One technicians for herds with usable data, 34 were from herds that used sand or other inorganic bedding and 14 from herds with rubberised walking surfaces.

The general type of facilities used to house lactating cows, dry cows, and heifers were described by asking about the

https://doi.org/10.1017/S0962728600002633 Published online by Cambridge University Press

housing system (tie-stall, free-stall, bedded pack), type of ventilation in the barn (none, fans, sprinklers, tunnel), number of stalls, type of bedding (sand, sawdust, mattresses, straw, or other), use of rubber flooring in walkways, and the age of facilities. Some herds used more than one type of housing system for lactating cows, so groups of tie-stalls only (n = 191), free-stall only (n = 96), bedded pack only (n = 4), a mix of tie-stall and bedded pack (n = 7), a mix of free-stall and either a bedded pack or tie-stall (n = 18) were formed for the analysis. There were seven herds that bedded with lime only and were grouped with sand-bedded herds to form an inorganic bedding group. Two types of feeding strategies were compared: component feeding (CF) where hay, silages and grain are fed separately and TMR where all feed components are mixed into a single ration. Herds that mixed ration ingredients, but that also fed dry hay separately, were classified as TMR and feeding dry hay was analysed as a separate variable. The level of outdoor access was classified as complete confinement, exercise lot only, occasional pasture access, or daily pasture access when weather permitted. Weekly labour hours provided by the owner, the owner's family, full- and part-time employees were used to estimate the number of cows per employee. A 55-h work week was considered one full-time worker equivalent, and the number of lactating cows on the farm was divided by the total full-time worker equivalents for lactating cows to determine the number of cows per employee. The proportion (none, < 50% or ≥ 50%) of cows treated with bovine growth hormone (BGH), whether cows' tails were docked, whether cows were identified by name, and whether the farm used natural service bulls were also determined. The number of cows on the farm was divided by the number of stalls to determine the herd's stocking rate. Stocking rates were not available for bedded pack herds. Stocking rates were also used to identify herds that were overstocked. Some herds house fresh cows in a pen for a short period after calving. In such instances, there may be more cows than stalls available according to DHI records even though each lactating cow has a stall available and the barn is not truly overstocked. To accommodate such situations, herds were considered overstocked when the number of cows was > 103% of the available stalls rather than > 100%.

Some farms chose not to report specific items. In most instances, there were a sufficient number of herds with the same missing information to form a class of 'not reported'. The exception was three herds not reporting BGH use and two not reporting hoof trimming, which were simply removed from analysis of BGH and hoof trimming, respectively.

Dairy Herd Improvement records were received from Dairy Records Management Systems (DRMS, Raleigh, NC, USA) in January 2006. Records were used to determine the proportion of the lactating dairy herd that died, the proportion of cows that died or that were sold to slaughter between 21 days prior to a calving due date through 60 days post calving (CULL60), and the proportion of a herd that was at least six years of age and in fifth or higher parity (AGED). There is no distinction made in the DHI system between cows that died naturally or were euthanised. In order to calculate mortality rate, CULL60 and AGED, only records from 2005 were considered because they contained completed annual records and additional records were not available from DRMS at the time of analysis.

Mortality rate, CULL60 and AGED were expressed primarily as, *n/(mean cow inventory for 2005)*, where n = the number of cows that died, left the herd between –21 and 60 days relative to calving, or were aged cows. The magnitude of cow death and culling can also be expressed relative to the population at risk (Fetrow *et al* 2006; Thomsen & Houe 2006). The primary cows at risk for death are those near calving, so a second measure considered was *n/(total calvings in 2005)*, where n = the number of cows that died or that left the herd between –21 and 60 days relative to calving. When expressed as a proportion of cows calving in 2005, we refer to mortality risk (as opposed to mortality rate) and CULL60 risk (as opposed to CULL60).

Five HMS were identified from the data: herds with a free-stall that did not allow outdoor access for lactating cows (complete confinement free-stalls, n = 37), herds with a free-stall that did allow outdoor access for lactating cows (n = 76), tie-stalls that did not allow outdoor access for lactating cows (complete confinement tie-stalls, n = 52), tie-stalls that allowed outdoor access and that fed TMR (n = 72), and tie-stalls that allowed outdoor access and that were CF (n = 77). In order to avoid the development of HMS with a small number of observations and because each management factor was analysed independently, HMS further broken down by the type of outdoor access and other management factors were not considered. Additionally, herds with a bedded pack only or with a mix of tie-stall and bedded pack were grouped with tie-stalls due to their relative infrequency. Herds with a mix of free-stall and bedded pack or a mix of free-stall and tie-stalls were grouped with free-stalls.

Statistical analysis

All cow welfare outcomes were evaluated with a multivariable linear regression model in SAS (SAS Institute 2000) and results are expressed as estimated marginal means (EMM), which were the means of each management level after adjusting for all other effects in the model. An initial analysis was conducted to compare mortality rate, mortality risk, CULL60, CULL60 risk, and AGED between herds of varying sizes that did or that did not complete a questionnaire. The independent variables included a covariable for the proportion of Holstein, a variable that was developed to indicate whether heifers that die or are sold in the interval between their first calving and what would have been their first milk test date are recorded (1 = reported for herds with ≤ 100 cows, 2 = reported for herds with > 100 cows, 3 = not reported for herds with ≤ 100 cows, and 4 = not reported for herds with > 100 cows), herd size group, an indicator of questionnaire availability (1 = questionnaire completed, 0 = not completed) and the interaction of herd size group and questionnaire availability. Herd size groups corresponded to herds in

https://doi.org/10.1017/S0962728600002633 Published online by Cambridge University Press

the bottom quartile (≤ 46 cows), middle 50% (46 to 93 cows) and highest quartile (≥ 93 cows) of herds that completed a questionnaire. Herd size groups were the same for herds that did not complete a questionnaire with the exception that there were sufficient observations to form a separate large herd group (≥ 200 cows).

A second group of analyses included only herds that completed a questionnaire. Mortality risk and CULL60 risk were not considered after the initial analysis. The effect of each management factor included in the questionnaire on the welfare outcomes was evaluated with models that included independent variables for the proportion of Holstein, heifer culling status and the farm's response to one individual question. The analysis was repeated for each question and for the HMS described previously. Marginal means for mortality rate and CULL60 for HMS were estimated for all parities and separately for ≥ third parity because death and culling are more frequent in older cows (Faye & Pérochon 1995; Thomsen *et al* 2004; Dechow & Goodling 2008). Additionally, mortality rate and CULL60 for ≥ third parity are not influenced by whether heifers that die or are sold in the interval between their first calving and what would have been their first milk test date are recorded.

Models were subsequently expanded to include independent variables for HMS and the response to one individual question in order to identify factors with a significant influence on survival that were not confounded with HMS. The analyses of HMS were also expanded by including AGED as a covariable nested within HMS to account for the impact of age on the likelihood of culling or death.

Herd mortality, CULL60 and AGED were considered the primary indicators of cow welfare in this study. Additional indicators that were available included the mean daily milk yield of all cows in the herd, mean lifetime-to-date milk yield of all cows (total milk yield of all lactations at culling or the end of 2005 for cows remaining in the herd), somatic cell score (SCS), the proportion of cows with a milk protein percentage that was higher than milk-fat percentage on DHI test day (fat-protein inversion), the mean milk-fat percent on a cow's first test day during lactation (FAT1), and the change in mean milk-fat test from FAT1 to the nadir milk fat percent (FATN). Estimated marginal means for these additional variables were estimated for HMS and the model included AGED within HMS. The lone exception was lifetime-to-date milk yield which was analysed without AGED because the purpose of analysing the trait was to determine HMS with cows that remained productive over a longer period of time and would be redundant with mean daily milk yield if the age component is removed.

Results

Descriptive statistics

Descriptive statistics for management factors related to housing are reported in Table 1 and descriptive statistics for other management factors and welfare outcomes are reported in Table 2. The mean herd mortality rate across all herds was 4.5% and ranged from 2.6% in tie-stalls with outdoor access and CF to 6.0% for confinement free-stalls (Table 2). The mean CULL60 across all herds was 7.1%, and mortality rate (7.4%) and CULL60 (13.5%) were higher in ≥ third lactation.

Cows in completely confined free-stalls and tie-stalls were housed in the newest facilities. A 48% increase in median cows per worker when compared to the median of all herds, frequent use of BGH (78 vs 38% for all herds), and tail-docking (70 versus 31% for all herds) were evidence that labour and economic efficiency were emphasised in confined free-stalls. Confinement free-stalls were the most likely to use natural service herd bulls (29.7 versus 19.7% for all herds) and trim hooves ≥ 2 times per year (76 vs 61% for all herds). Herds that used inorganic bedding were primarily free-stalls (35 out of 38) and almost all free-stalls fed TMR.

Twenty percent of free-stalls were overstocked versus 10% of tie-stalls. Tie-stalls that allowed outdoor access were more likely to be overstocked than confinement tie-stalls and presumably held some cows in the pasture or barn yard until other cows were milked and a stall was available for milking. Cows were named in a higher proportion of tie-stalls than free-stalls. Dry cows and heifers in all systems were more likely to have pasture access and be fed free-choice dry hay than lactating cows.

Herd size and questionnaire availability

The proportion of Pennsylvania herds with usable DHI data and with a completed questionnaire was 9.9%. Among herds with completed questionnaires, the median herd size was 62 lactating plus dry cows. The median herd size was 57 cows for 2,872 herds that did not complete a questionnaire.

Estimated marginal means are reported for herd size within questionnaire participation status in Table 3. Mortality risk was 0.4 to 1.1% higher and CULL60 risk was 0.9 to 1.4% higher than mortality rate and CULL60, respectively. The difference between them reflects calving intervals that were greater than 12 months in length. Mortality and CULL60 were significantly less for the small (≤ 46) and mid-sized herds (> 46 to ≤ 93) than herds with ≥ 200 cows. In only one instance (mortality risk for herds with ≥ 46 cows) was there a significant difference for any measure of survival within the same herd size class between herds that participated or that did not participate in the questionnaire.

The regression of CULL60 on the percentage of a herd that was Holstein was significantly positive, but not strong. A herd that was 100% Holstein was expected to have a 1.1% higher CULL60 than a herd that was 0% Holstein (1.6% for CULL60 risk). Likewise, a pure Holstein herd was expected to have a 3.7% lower proportion of AGED, which was significant. The regression of mortality rate (0.2% for a pure Holstein versus non-Holstein herd) and mortality risk (0.4% for a pure Holstein versus non-Holstein herd) were positive, but not significant.

Table 1 Descriptive statistics for housing-related questions by herd management system.

	Free-stalls		Tie-stalls			All
	Confine	Outdoor	Confine	Outdoor TMR†	Outdoor CF‡	
Number of cows (median)	153	89	62	57	44	62
Number of cows (maximum)	806	746	136	157	93	806
Facility age (median)	8	17	8	13	13	12
Herds not reporting facility age (n)	4	7	8	9	12	40
Stocking density (median %)	85	94	90	91	91	92
Herds overstocked (n)	6	17	1	11	8	43
Herds lacking stocking statistics (n)	8	13	2	9	2	34
No outdoor access for lactating cows (n)	37	0	52	0	0	89
Exercise lot for lactating cows (n)	0	23	0	25	5	53
Some pasture for lactating cows (n)	0	16	0	23	17	56
Daily pasture for lactating cows (n)	0	37	0	24	55	116
No outdoor access for dry cows (n)	6	2	7	3	2	20
Exercise lot for dry cows (n)	2	7	3	7	4	23
Some pasture for dry cows (n)	8	9	7	6	7	37
Daily pasture for dry cows (n)	21	58	35	56	64	234
No outdoor access for heifers (n)	8	5	4	1	4	22
Exercise lot for heifers (n)	0	6	54	4	2	17
Some pasture for heifers (n)	6	9	4	10	5	34
Daily pasture for heifers (n)	23	56	39	57	66	241
Tie-stall for lactating cows (n)	3	5	51	69	77	205
Tie-stall for dry cows (n)	0	0	8	9	24	41
Tie-stall for heifers (n)	0	1	1	0	0	2
Free-stall for lactating cows (n)	37	76	0	0	0	113
Free-stall for dry cows (n)	17	19	3	4	4	47
Free-stall for heifers (n)	12	17	6	4	3	42
Bedded pack for lactating cows (n)	6	4	1	8	2	21
Bedded pack for dry cows (n)	18	50	43	59	59	229
Bedded pack for heifers (n)	25	50	42	63	71	251
Ventilation: fans only (n)	18	45	5	6	23	97
Ventilation: natural (n)	1	9	0	3	14	27
Ventilation: fans with sprinklers (n)	10	18	3	6	1	38
Ventilation: tunnel (n)	8	4	44	57	39	152
Bedding: inorganic (n)	7	28	1	2	0	38
Bedding: mattresses with sawdust (n)	20	20	32	39	38	149
Bedding: mattresses only (n)	3	3	1	4	11	22
Bedding: organic only (n)	7	25	18	27	28	105

† Total mixed ratio;
‡ Component feeding.

Table 2 Descriptive statistics for non-housing-related questions by herd management system.

	Free-stalls		Tie-stalls			All
	Confine	Outdoor	Confine	Outdoor TMR†	Outdoor CF‡	
Mean proportion of Holstein cows	96.2	92.6	96.7	95.1	90.8	93.9
Heifer culling reported between calving and 1st DHI test (n)	19	12	14	9	8	62
Cows per worker (median)	68.2	57.3	44.7	41.5	30.8	46.1
Mean proportion of labour from the farm's owner and family (%)	50	88	100	100	100	100
Herds not reporting labour statistics (n)	5	6	5	15	11	42
Lactating cows fed a TMR (n)	37	68	42	72	0	219
Dry cows fed a TMR (n)	33	45	32	45	0	155
Heifers fed a TMR (n)	24	32	26	32	0	114
Lactating cows fed free-choice hay (n)	2	27	11	20	61	121
Dry cows fed free-choice hay (n)	16	59	37	56	63	231
Heifers fed free-choice hay (n)	24	61	38	54	63	240
Tails docked (n)	26	25	18	11	17	97
Cows given name (n)	9	34	30	49	61	183
Natural service bull used (n)	11	16	10	4	21	62
BGH not used (n)	8	51	21	54	58	192
BGH used on 1 to < 50% of cows (n)	11	17	16	11	8	63
BGH used on > 50% of cows	18	8	14	7	9	56
BGH use not reported (n)	0	0	1	0	2	3
Hooves trimmed on heifers (n)	7	4	3	2	2	18
Hooves not trimmed on cows (n)	0	0	1	1	2	4
Hooves trimmed once per year (n)	9	36	16	29	47	137
Hooves trimmed two or more times per year (n)	28	39	34	42	48	191
Hoof-trimming practices not reported (n)	0	1	1	0	0	2
Mortality rate (%)	6.0	5.5	4.6	4.4	2.6	4.5
CULL60 rate (%)	8.6	8.9	7.3	6.7	4.9	7.1
AGED (%)	6.4	10.2	9.2	10.4	14.4	10.7
Mortality rate in third or greater lactation (%)	10.0	9.3	8.2	7.3	3.8	7.4
CULL60 rate in third or greater lactation (%)	17.6	16.3	15.8	12.1	8.4	13.5
Mean daily milk yield (kg)	32.9	30.1	34.5	32.6	29.8	31.7
Mean lifetime-to-date milk yield (kg)	20,160	20,940	22,112	22,405	22,886	21,855
Mean somatic cell score	2.92	3.02	2.73	3.03	2.86	2.92
Proportion of cows with fat-protein inversions (%)	14.1	15.1	11.9	13.1	8.6	12.4
Mean fat % on first test day	4.28	4.15	4.13	4.18	4.21	4.18
First test day fat % – nadir fat %	1.39	1.29	1.24	1.32	1.27	1.29

† Total mixed ratio;
‡ Component feeding.

Table 3 **The number of herds (n herds) and estimated marginal means for mortality rate and mortality risk, the rate and risk of culling by 60 days in milk (CULL60), and the proportion of aged cows (AGED) for herds of varying size (n cows) and that did or did not participate in the questionnaire.**

Cows (n)	Questionnaire participant	Herds (n)	Rate		Risk		
			Mortality (%)	CULL60 (%)	Mortality (%)	CULL60 (%)	Aged (%)
n ≤ 46	No	877	4.3^{ab}	6.6^{a}	5.4^{a}	8.0^{a}	12.2^{a}
n ≤ 46	Yes	78	3.5^{b}	6.9^{ab}	3.9^{b}	7.8^{ab}	12.6^{a}
46 < n ≤93	No	1,430	4.6^{ac}	7.3^{b}	5.4^{a}	8.5^{bc}	10.8^{b}
46 < n ≤93	Yes	159	4.6^{bcd}	7.6^{bc}	5.3^{ab}	8.5^{acd}	10.3^{b}
93 < n ≤200	No	435	5.1^{de}	8.4^{cd}	5.9^{ac}	9.4^{de}	8.7^{c}
n > 93	Yes	77	5.1^{adf}	8.5^{cd}	5.5^{abd}	9.5b^{df}	8.2^{cd}
n > 200	No	132	5.8^{ef}	8.7^{d}	6.7^{cd}	10.0^{ef}	7.1^{d}

$^{a-f}$ Estimated marginal means in a column that do not share a common superscript differ significantly (*P* < 0.05).

Table 4 **Estimated marginal means for mortality rate, the proportion of a herd exiting by 60 days in milk (CULL60), the proportion of aged cows (AGED), and the proportion of herds with a given response (%) for housing-related questions that were significantly associated with one or more indicators of survival.**

Question	Response	%	Mortality	CULL60	AGED
Level of outdoor access for lactating cows	No outdoor access	28	5.2	8.2	8.0^{a}
	Exercise lot only	17	5.0	8.7	8.8^{a}
	Some pasture	18	4.4	7.5	10.2^{b}
	Daily pasture	37	4.2	7.9	11.5^{b}
Housing system	Tie-stall only	60	3.5^{ac}	6.4^{ac}	10.6^{a}
	Free-stall only	30	5.7^{b}	9.6^{b}	8.4^{b}
	Bedded pack only	1	4.0^{bc}	6.3^{bc}	11.4^{ab}
	Tie-stall + bedded pack	2	3.0^{bc}	6.5^{bc}	9.5^{ab}
	Free-stall + bedded pack	6	5.8^{b}	8.7^{b}	8.3^{ab}
Dry cows housed in a free-stall[1]	No	85	4.8	7.9	10.0^{a}
	Yes	15	4.9	8.8	7.3^{b}
Heifers housed in a free-stall[1]	No	86	4.5^{a}	7.9	9.9^{a}
	Yes	14	5.9^{b}	9.1	7.2^{b}
Heifers housed on a bedded pack	No	20	6.0^{a}	9.6^{a}	7.7^{a}
	Yes	80	4.5^{b}	7.7^{b}	9.8^{b}
Bedding type for lactating cows[2]	Inorganic	12	6.1^{a}	10.0^{a}	9.5
	Organic	34	4.9^{ab}	7.6^{bc}	8.7
	Mattress with sawdust	47	4.4^{b}	8.0^{bc}	9.6
	Mattress only	7	5.3^{ab}	8.4^{ac}	10.2
Stocking density for lactating cows[2]	≤ 80%	22	6.2^{a}	9.9^{a}	9.1
	81–100%	44	4.7^{b}	7.9^{b}	9.7
	> 100%	23	4.1^{b}	7.2^{b}	9.1
	Not reported	11	5.0^{a}	8.4^{a}	9.1
Rubber walkways for lactating cows[3]	No	92	4.6^{a}	7.7	9.8
	Yes	8	2.3^{b}	6.7	10.0
Dry cows housed in a tie-stall[3]	No	87	4.3	7.4^{a}	9.8
	Yes	13	5.3	9.7^{b}	10.4

[1] AGED remained significantly different after adjusting for herd management system; [2] CULL60 remained significantly different after adjusting for herd management system; [3] Estimated marginal means after adjusting for the effect of herd management system for variables that were not significant without the effect of herd management system included in the model.
$^{a-c}$ Estimated marginal means in a column that do not share a common superscript letter are significantly different (*P* < 0.05).

Table 5 Estimated marginal means and associated *P*-values for mortality rate, the proportion of a herd exiting by 60 days in milk (CULL60), the proportion of aged cows (AGED), and the proportion of herds with a given response (%) for non-housing-related questions that were significantly associated with one or more indicators of survival.

Question	Response	%	Mortality	CULL60	AGED
Lactating cows fed a TMR[1]	No	30	2.9[a]	6.3[a]	12.7[a]
	Yes	70	5.3[b]	8.5[b]	8.6[b]
Dry cows fed a TMR[1,2]	No	51	3.6[a]	6.7[a]	12.0[a]
	Yes	49	5.4[b]	8.8[b]	8.0[b]
Heifers fed a TMR[1]	No	64	4.1[a]	7.4[a]	11.3[a]
	Yes	36	5.5[b]	8.8[b]	7.4[b]
Lactating cows fed free-choice hay	No	62	5.2[a]	8.5[a]	8.9[a]
	Yes	38	3.9[b]	7.1[b]	10.6[b]
Dry cows fed free-choice hay[2]	No	27	5.1	8.9[a]	8.5
	Yes	73	4.7	7.7[b]	9.8
Proportion of total labour performed by owner and/or family members [1,2]	≤ 66%	22	5.6[a]	8.8[a]	7.6[a]
	67–99%	14	4.9[ab]	7.9[a]	11.1[b]
	100%	51	4.0[b]	8.0[a]	10.6[b]
	Not reported	13	4.7[ab]	6.0[b]	8.9[ab]
Frequency of hoof trimming[3]	None or one time annually	45	4.2[a]	7.5[a]	10.5[a]
	Twice or more annually	55	5.3[b]	8.5[b]	8.6[b]
Cows per worker equivalent[2]	≤ 33	22	3.9[b]	7.4[ab]	12.7[b]
	34–65	44	4.7[ab]	8.4[a]	9.3[ab]
	≥ 66	21	5.3[a]	8.8[a]	8.9[a]
	Not reported	13	4.8[ab]	6.0[b]	9.0[ab]
Percentage of cows injected with BGH[1]	None	61	4.7	7.9	10.7[a]
	< 50%	20	4.9	8.6	8.7[b]
	≥ 50%	19	5.2	8.3	7.1[b]

[1] AGED remained significantly different after adjusting for herd management system; [2] CULL60 remained significantly different after adjusting for herd management system; [3] Mortality rates remained significantly different after adjusting for herd management system.
[a–b] Estimated marginal means in a column that do not share a common superscript letter are significantly different ($P < 0.05$).

Association of mortality, CULL60, and AGED with housing system

Results for questions in Table 1 with EMM that were significantly associated with mortality rate, CULL60, or AGED are reported in Table 4. Most survey responses were not significantly associated with mortality rate, CULL60 or AGED after adjusting for HMS. Two questions (rubber walkways for lactating cows and dry cows housed in a tie-stall) were significant only after adjusting for HMS. Estimated marginal means for those two responses are reported from the model that included HMS, whereas EMM for all other variables were from models that did not include HMS.

Free-stall housing for any class of animals had an unfavourable association with one or more welfare outcome. Free-stall housing for lactating cows was associated with significantly higher mortality rate, significantly higher CULL60 and significantly lower AGED than tie-stalls. Free-stalls for heifers and dry cows were also associated with significantly lower AGED, and free-stalls for heifers were associated with significantly higher mortality rate than herds without free-stalls. Herds with free-stalls were not significantly different for mortality rate, CULL60 or AGED than herds with both free-stalls and bedded packs, and the same was true of tie-stall only versus tie-stalls with bedded packs. Herds with a bedded pack were numerically similar to tie-stalls for mortality rate, CULL60 and AGED; however, the measures for bedded packs were not significantly different from any other housing system due to their relative infrequency in this dataset. After adjusting for the effect of HMS, housing dry cows in tie-stalls was associated with significantly higher CULL60. Heifers housed on a bedded pack had a significantly lower mortality rate, CULL60 and higher AGED. This effect was not significant after adjusting for HMS. Likewise, effects of bedding (higher mortality and CULL60 in herds with inorganic

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Table 6 Estimated marginal means for the proportion of aged cows (AGED) and for mortality rate and the proportion of a herd exiting by 60 days in milk (CULL60) with and without an AGED covariable.

	All parities		≥ Third parity		
	CULL60	Mortality	CULL60	Mortality	AGED
No AGED covariable					
Free-stall/confined	9.1[ab]	6.4[a]	18.4[a]	10.6[a]	6.4[a]
Free-stall/outdoor	9.6[a]	5.4[ab]	17.1[a]	9.3[a]	9.6[b]
Tie-stall/confined	7.2[bc]	4.1[bc]	14.9[ab]	7.5[ab]	9.4[ab]
Tie-stall/outdoor/TMR	7.0[c]	3.9[c]	11.7[b]	6.5[b]	10.2[b]
Tie-stall/outdoor/CF	5.3[d]	2.0[d]	8.2[c]	3.1[c]	13.8[c]
AGED covariable					
Free-stall/confined	9.7[a]	8.3[a]	18.3[a]	12.4[a]	
Free-stall/outdoor	9.5[a]	5.4[b]	16.6[a]	9.1[ab]	
Tie-stall/confined	7.0[b]	3.9[c]	14.0[ab]	7.0[bc]	
Tie-stall/outdoor/TMR	6.9[b]	3.9[c]	11.6[bc]	6.4[c]	
Tie-stall/outdoor/CF	5.1[c]	2.0[d]	8.4[c]	3.1[d]	

[a-d] Estimated marginal means in a column that do not share a common superscript differ significantly ($P < 0.05$).

Table 7 Estimated marginal means for somatic cell score (SCS), the proportion of fat-protein inversions (FPI), daily milk yield, lifetime-to-date milk yield, first test day fat percent, and first test day fat percent – nadir fat percent (changes in fat %).

	Free-stalls		≥ Tie-stalls		
	Confine	Outdoor	Confine	Outdoor TMR[1]	Outdoor CF[2]
SCS	3.04[a]	2.99[a]	2.64[b]	2.96[a]	2.71[b]
FPI (%)	13.94[ab]	14.45[a]	10.74[bcd]	12.06[ac]	8.27[d]
Daily milk (kg)	32.25[ab]	30.51[a]	34.99[c]	33.43[b]	31.57[a]
Lifetime-to-date milk yield (kg)	19,802.45[a]	20,768.50[ab]	22,092.77[bc]	22,376.59[c]	23,052.82[c]
First test day fat (%)	4.27	4.16	4.16	4.20	4.23
Change in fat (%)	1.36	1.29	1.22	1.30	1.29

[a-d] Estimated marginal means in a row that do not share a common superscript letter are significantly different ($P < 0.05$).
[1] Total Mixed Ration; [2] Component feeding.

bedding than herds with mattresses and sawdust) were significant before, but not after, adjustment for HMS. Herds with low stocking densities (≤ 80%) had significantly higher mortality rates and CULL60, and the association with CULL60 was significant after adjustment for HMS.

Association of mortality, CULL60, and AGED with non-housing management factors

Results that were significantly associated with mortality, CULL60, or AGED are reported in Table 5 for questions relating to feeding practices, labour management, foot care, and other management factors. Feeding TMR to heifers, dry cows, or lactating cows was significantly and unfavourably associated with all three measures of survival (Table 5). Feeding lactating cows dry hay was associated with significantly lower mortality rates, lower CULL60 and higher AGED, but not after adjusting for HMS; allowing dry cows access to free-choice dry hay was associated with significantly lower CULL60 after adjusting for the effect of HMS.

Herds with ≥ 66 cows per employee had significantly higher mortality and lower AGED than herds with ≤ 33 cows per employee (Table 5). Likewise, herds where family members provided 100% of the labour hours had significantly lower mortality rate and a higher proportion of AGED than herds where family members provided ≤ 66% of the labour hours. Differences in mortality rate among classes of cows per worker and the proportion of family labour hours were not significant after accounting for HMS. Herds that chose not to report labour hours had significantly less CULL60 both before and after adjusting for HMS.

Housing and management factors relating to foot care were associated with differences in mortality and AGED. More

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frequent foot trimming was significantly associated with higher mortality and lower AGED (Table 5), whereas providing rubber walking surfaces was significantly associated with lower mortality (Table 4).

The use of BGH was significantly associated with lower proportions of AGED and the effect remained significant after adjusting for HMS. Responses relating to the type of ventilation in the barn, naming cows, use of herd bulls, tail docking, and age of facilities were not significantly associated with mortality rate, CULL60 or AGED.

Association of mortality, CULL60, and AGED with herd management system

Associations of HMS with mortality rate, CULL60 and AGED are reported in Table 6. Tie-stalls with outdoor access and CF were the most optimal system for survival, with EMM for mortality rate, CULL60 and AGED that were significantly more favourable than the other systems. The proportion of AGED for such herds was approximately twice as high as in the least optimal system (completely confined free-stalls). Estimated marginal means for mortality rate were approximately 75% lower in tie-stalls with outdoor access and CF compared to completely confined free-stalls when AGED was included as a covariable. Differences for CULL60 followed the same trend as mortality rate.

Association of cow performance with herd management system

Table 7 reports EMM for additional performance measures. The results were in general agreement with those reported in Table 6 for mortality rate, CULL60 and AGED. Herd management systems with lower mortality and CULL60 and a higher proportion of AGED tended to have significantly higher lifetime-to-date milk yields, lower SCS, and a lower proportion of fat-protein inversions. Daily milk yield results were not in close agreement with other results, with completely confined tie-stalls associated with highest levels of daily milk yield. Measures related to milk-fat percent were not significant.

Discussion

The health of a cow that dies prematurely is clearly compromised, but some herds choose to not report mortality for various reasons (Dechow & Goodling 2008); therefore, additional measures of survival (CULL60 and AGED) were also considered. Almost no cows are voluntarily culled during the first 60 days of lactation (Dechow & Goodling 2008) because of the production potential for the remainder of lactation and because poor fertility or reproductive failure do not occur in early lactation. Thus, high levels of CULL60 indicate compromised cow health. Herds with higher levels of cow comfort and lower incidences of hock lesions were reported to have more mature cows (Fulwider *et al* 2007), which indicates a higher proportion of AGED as welfare improves. Overall herd culling rate was not considered because the decision to sell a cow for slaughter is often economic in nature, and many herds with high culling rates may simply be aggressively culling economically inferior cows (Fetrow *et al* 2006).

Mortality and CULL60 were expressed relative to both mean herd size and the number of calvings in 2005 when comparing herds of different sizes. Mortality risk (mortality relative to the number of calvings) was the preferred method of Thomsen and Houe (2006) because calving is the high risk period for cow death and all cows have the same number of high risk periods per lactation. A cow that calved twice in 2005 would not be distinguished from a cow that calved once in 2005 if mortality and CULL60 are expressed relative to average herd size. However, use of average herd size was the primary focus in this study because it is the method of determining culling rates in the DHI system (DRMS 1997), and the results are more comparable to other studies involving DHI data in the US (Smith *et al* 2000).

The general conclusions were the same regardless of the method chosen to estimate mortality and CULL60. Herds with ≥ 200 cows had significantly higher mortality and CULL60 and significantly lower AGED than small (≤ 46 cows) and mid-sized (> 46 to ≥ 93) herds. An unfavourable relationship between larger herd size and mortality has been reported previously (Smith *et al* 2000; Thomsen *et al* 2006; Dechow & Goodling 2008). Miller *et al* (2008) did not report an unfavourable relationship between herd size and mortality, but they eliminated data from the smallest herds and herds with low death rates prior to analysis.

The mean mortality rate of all herds in this study (4.5%; Table 2) is less than the mean mortality rate (5.9%) reported by Smith *et al* (2000) for the north region of the USA, which they defined as the Northeast (includes Pennsylvania) and Upper Midwest regions combined. This mortality rate (5.9%) was significantly lower than the rate reported for the Mid-south (7.0%) and South (7.7%) regions. The mean mortality rate for herds with < 100 cows in the north was reported to be 4.9 versus 6.5% for herds with ≥ 300 cows. Those rates are slightly higher than the corresponding mortality rate EMM reported for small and mid-sized herds (3.5 to 4.6%) and herds with ≥ 200 cows (5.8%) reported in Table 3. The proportion of cows that die has previously been reported to be lower in Pennsylvania than surrounding states in the Northeast (Hadley *et al* 2006).

The relationship between breed of cow and mortality rates are not consistent across studies. In this study, herds with a higher proportion of Holstein had higher CULL60 and lower AGED, but no significant relationship with mortality rate was found. In a comparison of within-herd breed differences, Miller *et al* (2008) reported higher mortality for Holstein than for Jerseys. The analysis was of a large dataset (> 2 million records) and though the results were significant, the effect of breed on mortality was not strong. In an analysis of > 7 million Danish records, the Jersey breed was reported to have higher mortality than Holstein (Thomsen *et al* 2004). It is likely that a farm's breed of choice is influenced by the management system of the farm, and differences among breeds may reflect differences in herd management in some instances. Crossbred cows in large California dairies were reported to have higher survival

https://doi.org/10.1017/S0962728600002633 Published online by Cambridge University Press

rates from calving to 30, 150 and 305 days postpartum than pure Holsteins in the same herds (Heins *et al* 2006), but they did not compare mortality rate differences.

McConnel *et al* (2008) used data from the National Animal Health Monitoring System Dairy (2002) survey to investigate the relationship of cow mortality with herd management factors and results were in general agreement with those reported here. They reported higher mortality rates in herds feeding TMR, that did not allow outdoor access, and that housed cows in free-stalls. The effects of outdoor access and housing were not significant in that study with a multivariable model that included TMR.

In contrast to the results reported in the current study, mortality risk was not different between free-stalls with cubicles and tie-stalls in a large Danish study (Thomsen *et al* 2006). This may indicate that lower mortality and CULL60 was due to management practices common among tie-stall herds that are not common among free-stall herds in the USA rather than an advantage of tie-stall housing. Both tie- and free-stalls had higher odds of mortality than herds with deep litter (Thomsen *et al* 2006). There was an insufficient number of herds with bedded packs to observe statistically significant differences from tie- or free-stalls in this study, but they were numerically similar to tie-stalls for mortality rate, CULL60 and AGED (Table 1) unless that herd also had a free-stall. Thomsen *et al* (2006) also reported significantly lower mortality in grazing herds and organic herds. In this study, herds with daily pasture access had toward a lower EMM for mortality (4.2%) than herds with no outdoor access (5.2%), which trended toward significance ($P < 0.15$).

Some factors were associated with mortality, CULL60 or AGED in a different direction than anticipated. High stocking density has previously been associated with poorer cow health and lameness (Stone 2004), but that was not observed in the current study. Herds with low survival rates may lack the necessary replacements to keep all stalls filled, resulting in low stocking rates. There were few herds (19) with a stocking density of > 120%, which may have limited our ability to detect adverse effects of overstocking. It was also expected that herds using inorganic bedding (primarily sand) might have lower mortality rates and CULL60 (Weigel *et al* 2003). Bedding was not significant after adjusting for HMS and 35 of 38 inorganically bedded herds were free-stalls. Hoof trimming was also associated with lower survival. It is likely that herds with poor foot health trim more frequently as opposed to hoof trimming directly causing lower survival.

A high proportion of fat-protein inversions is associated with an increase in ruminal acidosis (Bramley *et al* 2008). Dechow and Goodling (2008) reported that the odds of a fat-protein inversion in low vs high survival herds were 1.64:1. Herd management systems with the highest mortality rates and CULL60 (free-stalls) also had a significantly higher proportion of fat-protein inversions than tie-stalls that were CF. Relatively high mortality and CULL60 in free-stall systems might be due, in part, to higher levels of ruminal acidosis as indicated by higher fat-protein inversion rates. Likewise, free-stall systems had significantly higher mean SCS than either completely confined tie-stalls or tie-stalls that allowed outdoor access and that were CF. High SCS is a well established indicator of poor mammary gland health and high mastitis incidence (Schutz 1994), and herds with high SCS may have higher mortality and CULL60 due to the effects of mastitis. An increase in mortality when herd SCS increases has previously been reported (Thomsen *et al* 2006).

Improved cow comfort and higher levels of cow contentedness can allow cows to express higher levels of milk yield (Albright 1987), which has been used as an indicator of cow welfare (Bertenshaw *et al* 2009). Herds with higher milk yield have been reported to have lower mortality rates (Smith *et al* 2000; Thomsen *et al* 2006), which would support the use of milk yield as an indicator of improved cow care and well-being. However, a recent analysis suggested an antagonistic relationship between production level and mortality rate (Miller *et al* 2008). Dechow and Goodling (2008) reported similar milk-yield levels when comparing high and low mortality herds, but patterns of milk production varied. High mortality herds had significantly higher yield for young cows (first and second lactation), but significantly lower production for cows in fourth lactation and greater.

Both daily milk yield and lifetime-to-date milk yield were considered for the current study. Daily milk yield was highest for completely confined tie-stalls and lowest for free-stalls with outdoor access; however, daily milk yield was considered an indicator of cow welfare only under narrowly defined conditions in the current study for several reasons. Genetic selection for higher milk yield clearly does not improve cow health or well-being. Selection for higher yield is reported to be genetically correlated with greater incidences of mastitis in Holsteins (Vallimont *et al* 2009), Norwegian Reds (Heringstad *et al* 2007) and Finnish Ayrshires (Negussie *et al* 2008). Selection is also reported to increase other diseases, such as ketosis (Zwald *et al* 2004; Heringstad *et al* 2007), retained placenta (Heringstad *et al* 2007) and all diseases other than mastitis (Rogers *et al* 1999). Differences in the genetic merit of cows among herds could result in misleading conclusions with regard to the effect of herd environment if milk yield is used as a measure of cow well-being. The use of BGH similarly obscures the use of milk yield as a cow welfare indicator. It is also unclear that milk yield variation due to different nutritional levels is an accurate indicator of cow welfare because of the ability to up- or down-regulate milk production in response to energy availability. Additionally, if replacements are readily available then unhealthy cows can be replaced with a younger, healthier animal and mean milk yield across the herd will remain high.

Lifetime-to-date milk yield may be a more reliable indicator of cow welfare because attaining high lifetime yields indicate that nutritional, behavioural and cow comfort needs are met during the short term and that cow health is not

https://doi.org/10.1017/S0962728600002633 Published online by Cambridge University Press

compromised in the long term. Estimated marginal means for lifetime-to-date milk yield were highest for tie-stalls with outdoor access and CF, which is in agreement with the other welfare indicators.

Identifying cows by a name in place of a number was suggested to improve cow welfare in one study (Bertenshaw *et al* 2009), perhaps because such cows receive more individual attention. Tie-stall facilities were more likely to name cows, although naming cows was not significantly associated with mortality rate, CULL60 or AGED.

Pasture dairying reduces milk production costs (White *et al* 2002) and it appeared that owners of free-stalls with outdoor access were generally focused on producing milk with low input systems. Such herds used the oldest facilities, were the most likely to overstock their facilities and had the lowest daily milk production levels. They also had more cows per employee than tie-stall systems and were less likely to name their cows (Table 2), indicating less individual cow attention than in tie-stalls. Free-stalls with outdoor access would presumably provide behavioural benefits because cows are free to move around and have access to natural environments. However, such potential benefits did not manifest in lower mortality rates, CULL60 or AGED (when compared to tie-stalls) and suggests that those benefits alone were not sufficient to overcome other management or environmental deficiencies.

Despite evidence that tie-stalls are associated with higher survival and less mortality in this study and in McConnel *et al* (2008), tie-stalls are being eliminated as a result of welfare concerns in some countries (Sogstad *et al* 2005). Tie-stall-housed cows have been reported to have greater difficulty lying down, have a higher risk of injuries, such as hock inflammation and tramped teats, and have altered behaviour (Krohn & Munksgaard 1993; Krohn 1994; Regula *et al* 2004). However, less restricted movement in free-stalls did not result in improved cow welfare for the outcomes considered in this study when compared to tie-stalls. This could indicate that behavioural stress in tie-stalls is not severe, that behavioural stress has no discernable impact on mortality and other measures of survival or cow performance, or that behavioural stress in commercial USA free-stalls is under-appreciated. Cows in free-stalls are subject to competition during feeding, which alters feeding behaviour for submissive cows (Rioja-Lang *et al* 2009). Additionally, frequent pen movement in USA free-stalls are associated with environment change, rank establishment, competition, and stress (Nordlund *et al* 2006). Cows in tie-stalls are also reported to have less lameness and superior foot health when compared to cows in free-stalls (Cook 2003; Cramer 2008).

Fox (1983) suggested that housing in tie-stalls without daily outdoor exercise should be discontinued. However, such requirements would not have the intended effect of improving cow welfare across USA dairy farms if directed at tie-stalls only. If only tie-stall herds are required to improve cow welfare, they will be under more severe economic duress than competitors with free-stalls. Such a scenario would likely accelerate the trend toward confinement free-stalls, which were superior to confinement tie-stalls for none of the welfare outcomes considered here and were associated with higher mortality across all lactations before and after adjustment for AGED, higher CULL60 after adjustment for AGED, lower lifetime-to-date and daily milk yields, and higher SCS.

Feeding TMR was strongly associated with mortality in both the current study and in McConnel *et al* (2008). It is not clear whether TMR is directly responsible for lower survival, or if it is confounded with other herd management effects that predispose cows to lower survival. Stone (2004) reported that sub-acute ruminal acidosis was very prevalent in the USA dairy industry. An indicator of ruminal acidosis is depressed milk fat percentage and, subsequently, a higher likelihood of milk protein exceeding milk fat (Bramley *et al* 2008). Among tie-stall herds that provided outdoor access, feeding TMR was associated with a higher proportion of fat-protein inversions when compared to CF herds, indicating a higher proportion of cows at risk for acidosis. The results may indicate that cows preferentially sort through TMR to eat the concentrate portion of the TMR and avoid roughages more severely than realised. Sorting TMR has been associated with ruminal acidosis (DeVries *et al* 2008).

Animal welfare implications

The unfavourable effect of efficient management systems on cow mortality rates and other welfare measures suggests that cow well-being has been compromised in order to facilitate the economic survival of dairy farms.

Conclusion

There was agreement among several measures of survival and production that tie-stalls with outdoor access and CF were associated with increased cow health and welfare. Conversely, more efficient management systems (free-stalls, limiting pasture access, feeding TMR) were associated with higher mortality, CULL60 and a lower proportion of AGED cows.

Acknowledgements

This research was supported in part by agricultural research funds administered by The PA Department of Agriculture, USA. Data were provided by Dairy Records Management Systems (Raleigh, NC, USA), and the participation of Lancaster DHIA and Dairy One was greatly appreciated.

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https://doi.org/10.1017/S0962728600002633 Published online by Cambridge University Press