Cow Mortality in Midwest Dairy Herds

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ABSTRACT

On-farm dairy cow mortality is becoming a significant issue in the US dairy industry. A rise in on-farm mortality among cows indicates compromised cow welfare and also causes economic losses, including value of animal, its replacement cost, the loss of milk production and the extra labor used for its carcass disposal. Recently published studied showed increasing trends in dairy cow mortality in the US and in other countries. Mortality is the primary reason of cows leaving the herd. Various herd and cow level factors have been associated to the rise in mortality over the last couple of decades.

The aim of the current study was to describe the mortality patterns among cows in Midwest dairy herds and to identify the cow and herd level risk factors for on farm mortality. Approximately 5.9 million lactation records for cows from 10 Midwest states that calved between January 2006 and December 2010 were analyzed. Herd level mortality rate increased over time, and was higher in larger herds, herds with lower milk yield, and herds with less annual culling. Cow level mortality rate was higher in early lactation, in older cows, in winter and summer. Also, mortality was the main reason of cows leaving the herds in our study. The survival analysis indicated that the hazards of mortality were higher in cows with higher fat to protein ratio, higher fat%, lower milk protein %, higher 1st test day somatic cell score, higher milk urea nitrogen, cows with male calves, cows carrying multiple calves, and increased calving difficulty score. Cow mortality was higher in herds with increased percentage of still births, herds with higher somatic cell score and increased herd calving interval, and larger herds. Cows with higher

1st test day milk yield and in herds with higher milk yield had lower mortality hazards. The results of current study indicate that first test day records especially those indicative of negative energy balance in cows could be helpful to identify animals at high risk of mortality. It was also noted that higher milk yield did not seem to have harmful effects on mortality. In addition, the association between herd level factors and mortality indicated that management quality could be an important factor in lowering on-farm mortality thereby improving cow welfare.

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LITERATURE REVIEW

US dairy industry

The US dairy industry has substantially changed during the last 60 years. Greater volumes of milk per cow and larger herd size are the main characteristics of current dairy industry. The annual milk production per cow increased from 2,410 kg in 1950 to 5,394 kg in 1980 and to 9,593 kg in 2010 (USDA, 2012; Blayney, 2002). The number of dairy farms decreased from 3,681,627 in 1950 to 647,860 in 1970, to 192,660 in 1990 and to 62,500 in 2010. The cow inventory indicated that the proportion of cows reared in herds with herd size < 50 cows decreased from 93.7% in 1950 to 36.4% in 1980 and to 6.4% in 2010. Currently, the larger herds have the main share in total milk production. In 2011, 62.9% of the total milk was produced from herds with cows ≥ 500 followed by 12.6% (200-499 cows), 10.9 % (100-199 cows), 9.4% (50-99 cows), and 4.2 % (<50 cows). To meet the needs of transformation in herd structure, various management practices have been adopted such as reducing labor, more use of confinement housing, more concentrate-based diet, use of AI and ovulation synchronization programs, use of bovine somatotropin (bST), use of computers not only for records but also for feed formulation and even introduction of robotic milking (Bello et al., 2012).

Dairy cow mortality: a welfare issue

The current era of increased public awareness about farm animal welfare is very challenging for livestock industries. Dairy cows are under more scrutiny as it relates to animal well-being issues specially those kept in intensive dairy operations. In future years, the welfare of dairy cows will gain fundamental importance in the dairy sector. Public concern is present not only on the quality of the food products, but also the way these products are obtained (Veissier et al., 2012). For animal products like milk and meat, the conditions in which animals are reared and slaughtered are of prime importance (Miele et al., 2011). Welfare issues led the European Union to fund the Welfare Quality® project to develop a protocol for assessing animal welfare on farms and at slaughter plants. Third-party audit programs are good examples of the US dairy industry proactively moving in the right direction toward improving animal welfare (Jeffery, 20006).

On-farm mortality (euthanized at the farm or unassisted death) is one of the indicators of compromised cow welfare (Winckler et al., 2003; Thomsen et al., 2004; Thomsen and Houe, 2006; Rushen et al., 2008; Keyserlingk et al., 2009; Sandgren et al., 2009; De Vries et al., 2011). Cow mortality has been included in recent welfare assessment protocols for dairy cows (EFSA, 2009; WQ, 2009; EFSA, 2012). These protocols include animal-based welfare indicators which could be time consuming and expensive (Knierim and Winckler, 2009). De Vries et al. (2011) reviewed that on-farm mortality is one of those variables of routine herd data which are collected regularly and could be an easy and inexpensive way to estimate the welfare levels at the dairy farms.

Dairy cow mortality: an economic issue

Dairy cow mortality is not only a welfare concern but also an important economic issue. The loss of income from the sale of carcasses, decreased milk production, treatment cost during the period of disease or illness before death, increased replacement costs as the herd turnover rate increases, the extra labor used, as well as the dead animal disposal, all constitute financial losses (Thomsen et al., 2004; Alvasen et al., 2012). A brief description in following lines can explain the extent of economic loss due to mortality. As a result of increased mortality the culling rate increases. In 2011, the cost of replacement heifers was about $1420 (USDA-NASS, 2012). The average price of a dairy cow sold for slaughter was about $70/cwt in US dairy market (USDA-NASS, 2012). Although the price of culled cow is dependent on the condition score of the animal even then a 600 kg cow sold for slaughter instead of dying on farm could have earned about $500. The average disposal cost of a dead cow may vary from $25-70/cow (CWMI, 2002). Therefore, when cows die on the farm it can result in a considerable economic loss to the farmer.

Dairy cow mortality trends in the US

In the US, only a few studies had been published specifically related to dairy cow mortality until the year 2000 (Thomsen and Hue, 2006). However, mortality has been documented as a minor part of dairy cow removal studies in the literature as early as 1940. Seath (1940), while studying the influence of culling on the average production of Cow Testing Association herds, reported that the mortality in 37 Kansas dairy herds was 2.0% of total 1,883 cows during a 6-year period from 1930 to 1935. Asdell (1951) studied the culling patterns in Dairy Herd Improvement Association (DHIA) herds from 17 states for the period of 1932 to 1949 by looking at 2,792,188 records and reported that mortality was 1.1% of total cows. Meadows (1968) discussed the importance of traits other than milk production in breeding programs and reported that 1.4% of the cows left the Michigan DHIA herds because of death between 1963 and 1965. Milian-Suazo et al. (1989) explored the influence of production and diseases on culling in 34 herds in New York State from 1981 through 1985 and found that 1.2% of 7,763 lactations ended as death. Gardner et al. (1990) reported a mortality rate of 2% among 43 California dairy herds from 1986 to 1987, evaluated by the National Animal Health Monitoring System. Dematawewa and Berger (1998) analyzed the lactation records of Holstein cows obtained from the MidStates Dairy Records Processing Center (Ames, IA) for the period of 1980 to 1991 and observed a mortality rate of 2% during 305-day lactations. Mortality among dairy cows in those years remained between the ranges of 1% to 2% annually (Figure 1).

During the last two decades cow mortality rates increased in the US. Karuppanan et al. (1997) examined the records of 19,482 cows from 9 DHIA herds in California for the period of 1987 to 1992 and reported that mortality rate ranged from 0.8% to 6.4%. Young (2002) reported an increase in mortality levels of high and low producing Holstein and Jersey cows in the northwestern United States from around 5% in 1994 for Holsteins and Jerseys to 8% in 2001 for Holsteins and 7% for Jerseys. Smith et al (2000) analyzed the Dairy Herd Improvement Holstein herd summary records (n=11,259) for the year 1998 and found that the mortality rate ranged from 5.1% to 8.8% depending upon herd size, region and level of milk production. Stone et al. (2006) reported an average yearly mortality rate of 8.1%, with a range of 3.5 to 16.8% for 20 New York herds. Miller et al.

(2008) examined the National DHIA data (15,025,035 lactations in 45,032 herds) from 1995 through 2005 and found cow mortality as 3.1 % on lactation basis (number of cows died / total number of lactations per year) and 5.7% on cow basis (number of cows died / average number of cows per year). They also observed a steady increase in lactation mortality from 2% in 1995 to 4.6% in 2005. Similarly, the USDA-Animal and Plant Health Inspection Service-Veterinary Services-National Animal Health Monitoring System (NAHMS) Dairy 2007 survey reported that on-farm mortality increased from 3.8% for the January 1996 dairy cow inventory, to 4.8% for the January 2002 inventory, and to 5.7% for the January 2007 inventory (USDA, 2007). McConnel et al. (2009) studied 2,067 cows on a high-producing (approximately 11,500 kg of milk/cow per year), large (1,450 Holstein cows) commercial dairy in northern Colorado from March 1, 2005 through February 28, 2006 and reported cow mortality as 6.4% on lactation basis. Pinedo et al. (2010) studied approximately 3.6 million lactation records from 2,054 US dairy herds primarily in east of Mississippi river with herd size greater than 100 cows per herd and reported the yearly mortality rate as 6.6% for the period of 2001 to 2006. Although there is a variation in the methods used to calculate on-farm mortality in these studies, it can be seen that mortality levels among dairy cows did increase during the last 15 years or so in the US (Figure 1).

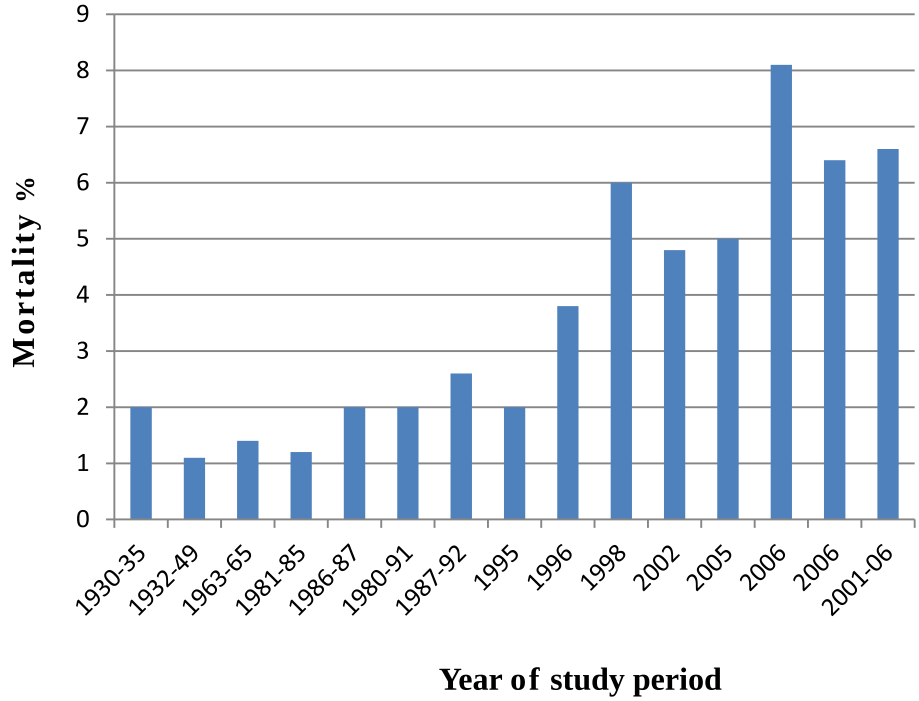

Figure 1: Dairy cow mortality in United States for the period of 1930 to 2010 (extracted from research articles)

Dairy cow mortality trends in Europe and others countries

Increase in dairy cow mortality in other parts of the world showed similar patterns as that of the US but with lesser extent. Early studies in Europe and other countries showed that the dairy cow mortality was 1 to 2% of total cows. Wright (1933) reported that out of 22,000 Scottish dairy cows, 1.1 % of the cows were removed from the herd as died. Similarly, Ward (1945) reported that 0.9 % of the total cows left the herd as died during 1939 to 1943 in New Zealand. Gracey (1960) reported the results of a survey carried on a random sample of 600 farms during 1954 and 1955 in Northern Ireland and found that 1.2 % of the cows died on farm during this period. O'Connor and Hodges (1963) compiled the results of a survey conducted by Milk Marketing Board of England and Wales in Private Milk Records herds for the period of October 1957 to September 1960 and reported that the average cow mortality was 1.0% of total number of cows for these years (n= approximately 800 herds for each year with average herd size of about 23 cows per herd). Barfoot et al. (1971) analyzed the economics of intensive health management in 157 Canadian dairy herds and reported a range of mortality rate from 1.9% to 2.5% during 1966-1968 depending upon the level of health care. Batra et al. (1971) studied the disposal patterns in 2,534 Holstein herds in Canada during 1967 to 1968. They found that mortality was 1.6% of total cows in expanding herds, 2.4% in shrinking herds, and 1.8% in herds with constant herd size. Amiel and Moodie (1973) carried out a survey on 41 dairy farms in the Brisbane area of Queensland, Australia, and reported that 1.2% of the total cows at risk died over a 12-month period from July 1968 to June 1969. Esslemont at al. (1985) reported 1.8% annual mortality in dairy cows in England. Gartner (1983) analyzed the removals from 18 dairy herds in the United

Kingdom for the period of 1973 to 1976 and observed a range of lactation mortality rate of 1.1 to 1.8% depending on the year. Harris (1989) reported a range of mortality from 1.1 to 1.4% depending upon age of cows in 384 dairy herds of New Zealand from 1985 to 1986. Faye and Perochon (1995) analyzed a 4-year survey data of 47 intensive dairy herds in Brittany (France) and reported a mortality rate of 0.96% for the period of 1986 to 1990 (n=8,945 lactations). Menzies et al. (1995) conducted a survey study in Northern Ireland during 1992 and reported 1.6% annual mortality rate among dairy cows. Esslemont and Kossaibati (1997) investigated the culling dynamics in 50 Friesian/Holstein dairy herds (average size 178 cows) in England from 1990 to1992 and reported an annual mortality rate of 1.6%. Stevenson and Lean (1998) studied the culling and deaths in 8 Australian dairy herds and reported that 4.3% of total cows left the herd as died during 1992 to 1994. Norgaard et al .(1999) studied the mortality trends on the basis of Danish incinerating plants data and documented that the crude death rate of cattle was around 2% from 1934 to 1960 and 4% from 1960 to 1980. However, the crude death rate remained between 3% and 4% during 1980 to 1993 (crude death rate was systematically overestimated). A survey study conducted on 249 dairy farms in the Republic of Ireland during 1996 demonstrated that yearly mortality was 1% (Leonard et al., 2001).

Thomsen et al. (2004) used the data from the Danish Cattle Database and a questionnaire survey to examine mortality among Danish dairy cows and observed that mortality risk increased from around 2% in 1990 to approximately 3.5% in 1999. Thomsen and Houe (2006) reviewed 19 studies related to dairy cow mortality covering the years from 1965 to 2006, and found that the average mortality was in the range of 1 to

5%. Thomsen and Sorensen (2008) documented that the mortality risk in Danish dairy increased from 2% in 1990 to 5% in 2005. Thomsen and Sorensen (2009) documented that in both Denmark and the US mortality among dairy cows is approximately 6%. Raboisson et al. (2011) used the French National Bovine Dataset Identification database and reported mortality rates of 3.7 and 3.8% for the year 2005 and 2006, respectively. Burow et al. (2011) studied the impact of summer grazing on dairy cow mortality for 391 Danish dairy herds (> 100 cows) in 2008 and documented that the mean annual mortality rate was 5.6%. Thomsen et al. (2012) studied the causes of death in Danish dairy herds and found that the annual herd-level mortality rate was 10.0% in 69 Danish dairy herds with an average herd size of 227 cows. Alvasen et al. (2012) studied the data for all Swedish dairy herds enrolled in the milk recording scheme between 2002 and 2010 and reported that the mortality rate, for herds with herd size ≥ 20 cows, gradually increased from 5.1 events per 100 cow-years in 2002-03 to 6.6 in 2009-10. The mortality trend in the countries other than US is shown in Figure 2.

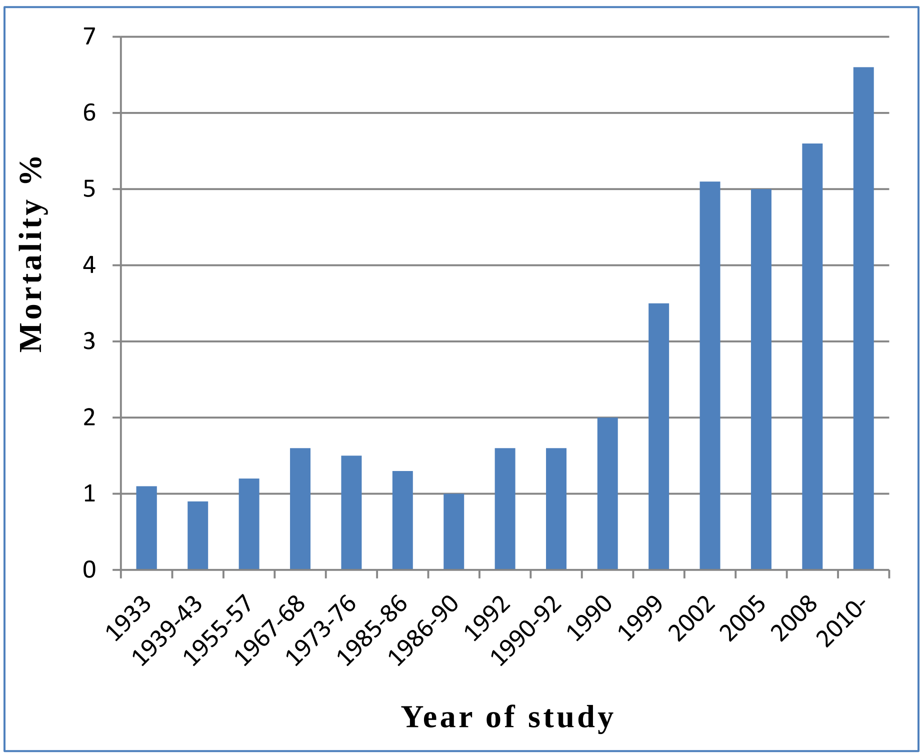

Figure 2: Dairy cow mortality in different countries (UK, Denmark, Sweden, New Zealand, Ireland, and France) for the period of 1933 to 2010 (extracted from research articles)

Genetic trends of dairy cow survival

The increased mortality rate could be due to changes in herd management, genetic changes, or a combination of genetic and herd management changes (Dechow et al., 2012). In the US, average age of Holstein cows has decreased substantially. Only a small proportion of cows survive beyond their fifth lactation (Nieuwhof et al., 1989; Hare et al., 2006). The mean number of parities for Holsteins declined from 3.2 in 1980 to 2.8 in 2004 (Hare et al., 2006). Thus, the age distribution of Holsteins has shifted toward younger cows (Brickell and Wathes, 2011). Approximately 37% of cows in large US herds are in their first parity, and 83% are within the first 3 parities (De Vries et al., 2010). As older cows are at higher risk of dying (McConnel et al., 2009; Pinedo et al., 2010; Raboisson et al., 2011), mortality rate should have been decreased with the decreased proportion of older cows; instead mortality increased over the same course of time (Dechow et al., 2012). Despite the negative phenotypic trends of productive herd life (Weigel, 2006), the genetic trends for survival have been favorable (AIPL, 2012), which suggest that declines in cow survival may be due to shifts in herd management rather than genetic selection (Dechow and Goodling 2008). Dechow et al. (2012) investigated the effect of sire selection on cow mortality and found that selection of sires with high productive life was associated with lower mortality. The positive genetic association between mortality and productive herd life indicates that the rise in mortality rate is not because of genetic changes rather the change in management strategies.

Natural or normal levels of mortality among dairy cows

In last few years, the cow mortality in dairy herds of United States and Denmark has been around 6% (Thomsen and Sorensen, 2009; Pinedo et al., 2010). Although concerns have been created over these increased levels of mortality among dairy cows, no standard exists for ‘natural’ or ‘normal’ levels of mortality in the dairy cow population (Thomsen and Houe, 2006). Recently, the Dairy Calf and Heifer Association (DCHA, 2009, 2010) developed performance standards for dairy calves and heifers and suggested acceptable mortality rates for calves and heifers according to age from birth to freshening across the United States. The recommended target mortality rates for calves under two months are < 5%; from 2 months to 4 months < 2%; 4 to 6 months,< 1%; for heifers of age 6 months to one year, < 1%; and from one year to freshening, < 0.5%. The range of dairy cow mortality among herds from 0% to ≥10 % (Faye and Perochon, 1995; Menzies et al., 1995; Thomsen et al., 2006) indicates that it is possible to achieve low levels of mortality and further research is needed to establish the minimum acceptable levels of mortality in dairy cows without compromising animal welfare and productivity.

Change in mortality ranking over time among reasons of cow disposal

Over time, the mortality among dairy cows has not only increased but also its ranking in culling reasons has been changed to a considerable extent, further increasing the welfare concerns about dairy cows. In earlier studies of cow disposal in the United States, the mortality was approximately 5 to 7 % of total culls (Table 1). However, in the relatively recent studies on cow removals, mortality proportion as a percent of total culls has increased. Bascom and Young (1998) reported mortality at 4th in ranking for reasons of culling (13% of total culls). Smith et al (2000) analyzed the DHIA records for the year 1998 and found that, for the northern states of the US, mortality was at 3rd (14.8% of total culls) in ranking for reasons of cows leaving the herd. In the most recent study, the mortality accounted for 20.6% of total culls and was the primary reason for cows leaving the herd (Pinedo et al., 2010). Figure 3 shows the change in mortality as a percent of total culls over time for the United States dairy cows. From the last 15 to 20 years there was an increase in the ranking of mortality among the reasons of cow disposal. The studies outside the United States also indicated the same trend in the ranking of mortality over the years (Table 1).

Risk factors of dairy cow mortality

Most of the studies focusing on dairy cow mortality, mainly described on-farm mortality relative to population characteristics and only few studies investigated the risk factors of dairy cow mortality (Raboisson et al., 2011). Similarly, Alvasen et al. (2012) reported that the associations between on-farm mortality and herd level characteristics have not been extensively studied. The factors influencing the on-farm cow mortality can be categorized into two groups: herd level risk factors (indicative of management style) and cow level risk factors (cow's own characteristics).

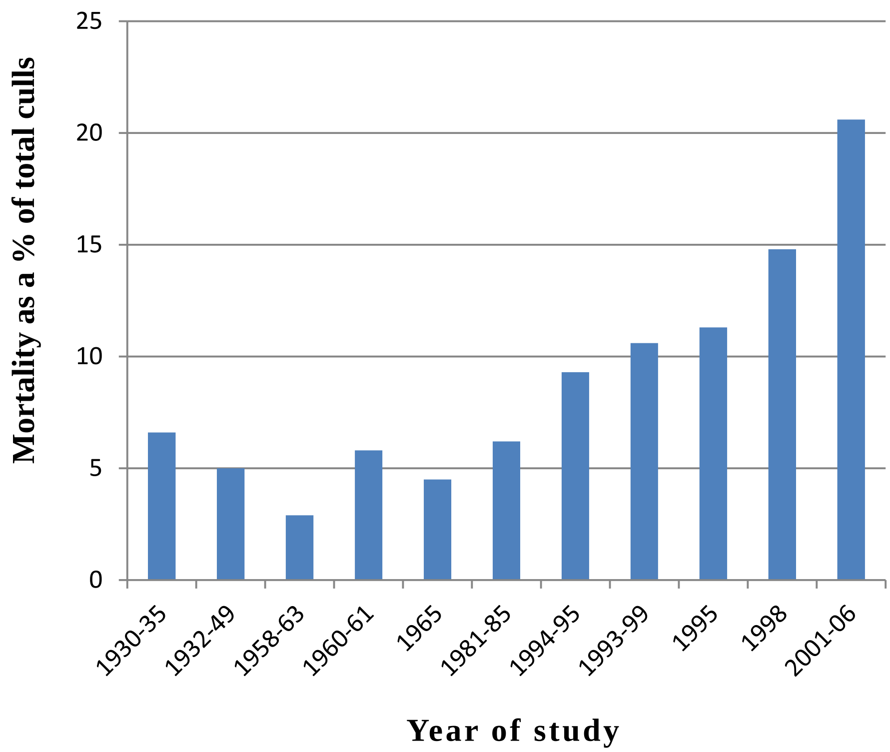

Figure 3: Dairy cow mortality as a % of total culls in United States for the period of 1930 to 2006 (extracted from research articles)

Herd level risk factors

Herd level milk yield has been reported as a risk factor for mortality in previous studies (Smith et al., 2000; Thomsen et al., 2006; Burow et al., 2011; Alvason et al., 2012). Alvason et al. (2012) showed 12%, 10% and 3% reduction in mortality rate herds with milk yield ≥ 9,981 kg, 9,291kg to 9,980 kg, and 8,525kg to 9,290 kg, respectively as compared to herds with milk yield < 8,525 kg. Likewise, Burow et al. (2011) reported that every 1,000 kg increase in energy corrected milk yield/cow-year was associated with 13% decrease in incidence of mortality. Similarly, Thomsen et al. (2006) documented a 7% decrease (odds ratio: 0.93) in mortality for every 1,000 kg increase of mean milk yield per cow-year. In addition, Smith et al (2000) observed a reduction in mortality from 7.7% to 7.1% and 5.9% for low (<7,258 kg), medium (7,258 to 9,072 kg) and high (> 9,072kg) producing herds, respectively. Herds with medium production (7258 to 9072 kg) had 7.1% mortality rate. Batra et al. (1971) also found a negative association between herd milk production and the percentage of cows that died among Canadian herds with constant herd size and expanding herd size. However, this association was statistically significant only for herds with expanding herd size. Similarly, Bascom and Young (1998) found numerically lower number of cows leaving the herd as died in herds with high milk production (11,400 kg) compared to herds with lower milk production (10,500 kg), although that difference was not statistically significant. However, Norgaard et al. (1999) studied the long term relationship between cow mortality and some factors and found that a higher level of physiological stress due to higher milk yield and concentrate consumption has led to increased dairy cow mortality in the overall herd population.

Increasing herd size has been consistently reported as one of the risk factor for increased mortality (Norgaard et al., 1999; Smith et al., 2000; Hadley et al., 2006; Thomsen et al., 2006; Dechow and Goodling, 2008; McConnel et al., 2008; Pinedo et al., 2010; Raboisson et al., 2011; Alvasen et al., 2012). Alvasen et al. (2012) described lower mortality rate (6.0%) for smaller herds (herd size, 50-99.9 cow-years) and highest mortality rate (7.5%) for larger herds (≥ 200 cow-years). Raboisson et al. (2011) reported a +2% change in cow mortality for every 10 cow-years increase in herd size. Pinedo et al. (2010) documented an increase of mortality rate from 5.8% for the herds with herd size of 100-200 cows to 9.6% for the herds with herd size > 3,000 cows. Norgaard et al. (1999) suggested that in larger herds, increased mechanization and less personal attention to the cows could be one of the reasons of increased dairy cow mortality. Contrary to these results, some studies either did not observe any association between herd size and mortality or indicated a favorable trend in mortality with increasing herd size. In an old Canadian study, no significant association between mortality percentage and herd size was observed (Batra et al., 1971). Menzies et al. (1995) did not find any effect of herd size on dairy cow mortality. However, Miller et al. (2008) observed a small but consistent decrease in death frequency as herd size increased. The variation in herd size is associated with differences in herd management practices thereby altering the cow behavior and might explain the difference in mortality rates with difference herd size (Dechow and Goodling, 2008).

Increased length in herd calving interval has been associated with increased mortality among dairy cows. Alvasen et al. (2012) observed that the risk of mortality was 22% higher in herds with relatively larger calving interval (average calving interval ≥

422.0 days compared with herds with smaller calving interval (average calving interval = 389.3 days. Likewise, Raboisson et al. (2011) reported a +1% change in cow mortality for every 10 days increase in calving interval. Similarly, McConnel et al. (2008) found that herds with average calving interval > 13.9 months had 78 % higher odds of mortality than herds with an average calving interval < 13 months.

Access to pasture for grazing has been associated with decreased dairy cow mortality (Thomsen et al., 2006; Burow et al., 2011; Dechow et al., 2011; Alvason et al., 2012). Alvason et al. (2012) observed that the regions of Sweden with a longer pasture period had lower cow mortality. Dechow et al. (2011) investigated the impact of management systems on welfare indicators in Pennsylvania herds and found that herds with daily pasture access had lower mortality (4.2%) than herds with no pasture-access (5.2%). Burow et al. (2011) studied the effect of grazing in 391 Danish dairy herds and found that for automatic milking herds, the mortality risk was 54% lower in grazing compared to zero-grazing herds, and in traditional milking herds, the mortality risk was 25% lower in grazing compared to zero-grazing herds. Thomsen et al. (2006) studied the effect of summer grazing on mortality and found that herds practicing summer grazing had 22% less mortality than herds that did not have access to pasture-grazing in summer.

Lower annual live culling rate and culling fewer cows in early lactation has also been associated with increased mortality (McConnel et al., 2008; Pinedo et al., 2010; Raboisson et al., 2011). McConnel et al. (2008) documented that herds with a low percentage of cows that were culled less than 50 days in milk (≤ 2.0%) were 1.97 times more likely to have a greater level of mortality than herds with a moderate level of cows culled less than 50 days in milk (2.1 to 20.8% culling). Pinedo et al. (2010) observed that the dairy cow mortality was 7.2, 6.6, and 5.6% in herds with lower (< 17.65%), medium (17.6-32.5), and higher (> 32.5) annual live culling rates, respectively Raboisson et al. (2011) observed that for French dairy cows, every 10% increase in culling rate was associated with a mortality rate change of -2.0 %.

Inconsistent association between have been reported between mortality and housing systems. In a larger Danish study (n= 6,839 herds), Thomsen et al. (2006) documented that the risk of mortality was lower in loose housing barns with deep litter than barns with free-stalls or tie-stalls. However, Husfeldt and Endres (2012) did not find any difference in dairy cow mortality between deep-bedded and mattress based free stalls. They reported mortality rates of 8.2% for herds with deep beds and 8.6% for herds with mattresses. In contrast, Dechow et al. (2011) found that free-stall housing for lactating cows was associated with significantly higher mortality rate than tie-stalls. However, herds with a bedded pack were numerically similar to tie-stalls for mortality rate. Similarly, McConnel et al. (2008) reported a higher mortality rate in herds that housed cows in free-stalls.

Increased herd level somatic cell score has been associated with increased on-farm mortality (Thomsen et al., 2006; Dechow and Goodling, 2008; Burow et al., 2011). Thomsen et al. (2006) reported a 16% increase in the risk of mortality for every 100,000 cell/ml increase in herd's average somatic cell count. Similarly, Burow et al. (2011) documented that every 100,000 cell/ml increase in herd's average somatic cell count was associated with 23% increase in the rate of mortality among dairy cows. Likewise, Dechow and Goodling (2008) reported that herds with lower mortality rate had lower somatic cell score indicating that the herds with lower mortality had better udder health.

The use of total mixed rations was associated with increased dairy cow mortality in some studies (Norgaard et al., 1999; McConnel et al., 2008; Dechow et al., 2011). McConnel et al. (2008) reported that the odds of mortality were 2.08 times greater in herds that used total mixed ration (TMR) compared to herds that did not use TMR. Similarly, Dechow et al. (2011) documented that the mean mortality rate was higher in herds that fed TMR to cows. Norgaard et al. (1999) concluded that a higher level of physiological stress due to higher yield and concentrate consumption led to increased mortality.

Mortality was higher in those herds which had higher proportion of purchased cows (Thomsen et al., 2006; Raboisson et al., 2011). Thomsen et al. (2006) documented that every 10% increase in the proportion of purchased cows was associated with 5% increase in dairy cow mortality. Raboisson et al. (2011) reported that with the increase in proportion of purchased cows in herds the change in mortality rate increased from +5% up to +15 % depending upon the extent of purchased cow proportion.

Some other management factors have also been associated with increased mortality. A couple of studies indicated that cow mortality was lower in organic herds compared to conventional herds (Thomsen et al., 2006; Alvason et al., 2012). The herds with higher proportion of family labor (100%) had lower mean mortality rate (4.0%) compared to herds with lower proportion of family labor (≤ 66%) with a mortality rate of 5.6% (Dechow et al., 2011). The herds with higher prevalence of lameness, respiratory problems and with more antibiotic use had higher mortality (McConnel et al., 2008). Regional differences in dairy cow mortality have also been observed (Smith et al., 2000; McConnel et al., 2008; Alvason et al., 2012) indicating that local physical environment, nutrition, and management could play a role in dairy cow mortality (McConnel et al., 2008).

Cow level risk factors

Cows producing more milk than their herd's mates seemed to have lower mortality. Pinedo et al. (2010) reported that the annualized mortality rate was lower (2.7%) in cows with cow-relative 305ME milk yield > 2,187 kg than the cows with cow-relative 305ME milk yield < -2,313 kg with annual mortality rate of 9.9%. Similarly Hadley et al. (2006) reported that cows producing 45 kg more milk than average 305ME milk yield were 0.5 to 1.7% less likely to be culled than the average producing cow. Dematawewa and Berger (1998) described that despite the negative genetic relationship between yield traits and survival, the positive phenotypic correlations (of about 0.1) between survival and yields indicated that preferential treatment by the dairy producer for high-yielding cows kept the mortality rates of high producing cows lower than the low producing cows. In contrast to these studies, Miller et al. (2008) found that death frequency increased by 0.4% when the average milk yields per cow increased by 1,000 kg in Holsteins. Similarly, Milian-Suazo et al. (1989) reported that high milk yield per day was associated with dairy cow mortality. They reasoned that high yielding cows might have been treated instead of being shipped for slaughter thereby dying at the farm, or high milk production could be a stress for such cows.

The early lactation period has been reported the highest risk period for mortality in dairy cows. In a recent French study, approximately 35 and 55% of the total deaths occurred during the first 30 and 100 days of lactation, respectively (Raboisson et al., 2011). Pinedo et al (2010) described that the proportion of cows died was highest after calving (57%) that decreased to 22% for 100 d, and 20% for 120 d after calving. Likewise, Miller et al (2008) reported that the death frequency was highest (17.3%) in early lactation (≤ 45 days after calving) followed by 46 to 90 days after calving (10.1%), 91 to 150 days after calving (8.5%), 150 to 250 days after calving (6.5%) and ≥ 251 days after calving (0.9%). Similar findings have been reported in other studies (Milian-Suazo et al., 1988; Faye and Perochon, 1995; Menzies et al., 1995; Thomsen et al., 2004; Hadley et al., 2006; Dechow and Goodling, 2008).

The period before and after calving (transition period) is a high-risk period for many diseases (Shanks et al., 1981; Dohoo et al., 1983; Markusfeld, 1993). Thomsen et al. (2004) reported that the primary causes of on-farm mortality were related to those disorders which are common during periparturient period, e.g. milk fever, left- and right-displaced abomasa, mastitis caused by *E. coli*, calving disorders and locomotor disorders. During this period a cow undergoes tremendous metabolic and endocrine changes related to parturition and the onset of lactation (Drackley et al., 2001). If the homeostatic mechanisms of the cow do not act effectively to respond to the changes in the body, disorders such as, milk fever or clinical hypocalcaemia, ketosis, retained fetal membranes, metritis, mastitis, and displacement of the abomasum may occur (Grummer, 1995; Goff and Horst, 1997). These diseases affect cows within two weeks after calving (Drackley, 1999). Some diseases that become clinically apparent in later stages of lactation, such as laminitis, ovarian cysts, endometritis and anestrus are related to the early postpartum (Goff and Horst, 1997). The high occurrence of locomotor disorders in first 3 months of lactation has been reported by Green et al. (2002). Shanks et al. (1981) also found that health costs were highest during the first 30 days after calving and suggested that most disorders were associated with initiation of the lactation rather than the period of peak daily milk production. Therefore this early period after calving is a high risk period of developing diseases related to the metabolic challenges of parturition and the beginning of lactation (Melendez and Risco, 2005) and could explain the higher incidence of on-farm mortality in early lactation.

The higher mortality with increasing parity has been reported previously (Faye and Perochon, 1995; Thomsen et al., 2004; Miller et al., 2008; Pinedo et al., 2010; Raboisson et al., 2011). The higher incidence of certain diseases related to increasing parity might be the reason of increased mortality among older cows (Thomsen et al., 2004).

The studies indicate that the mortality rates differ between the breeds. Alvasen et al. (2012) reported that herds with Swedish Holstein had 22% and 10% higher risk of mortality compared to herds with Swedish Red and with mixed breeds (Crossbred , Swedish polled and Swedish Jersey), respectively. Heins et al. (2012) reported that Holstein cows had higher mortality (5.3%) compared to crossbred cows (1.7%) during the first 305 d of the first lactation. Raboisson et al. (2011) observed higher mortality in Holstein compared to Montbeliarde and Normande in France. Thomsen et al. (2006) reported a higher mortality in Danish Holstein compared to Danish Jersey, Danish Red dairy, or other breeds (Danish Red Holstein, Ayrshire and crossbreeds). Miller et al. (2008) reported that although within-herd breed differences were small, Holstein cows had higher mortality than Jerseys. The difference in milk yield, incidence of common production diseases, as well as variation in size and conformation across the breed could explain the difference of mortality rate between dairy breeds. Dechow et al. (2011) did not find significant difference in mortality rate between the breeds; however, they argued that 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.

Causes of dairy cow mortality

Thomsen and Hue (2006) reviewed 19 studies between 1965 and 2006 that focused on dairy cow mortality and reported that 10 studies provided information about causes of on-farm deaths with a varying degree of detail. Although the categories used to describe the deaths were relatively uniform across studies and included accidents, calving disorders, digestive disorders, locomotor disorders, metabolic disorders, udder/teat disorders, other known reasons, and unknown reasons (Thomsen and Houe, 2006), some studies divided the specific cause of death only into 2 categories (Harris, 1989; Stevenson and Lean, 1998) whereas others into 8 or even more categories (Esslemont and Kossaibati , 1997; Thomsen et al.,2004). In those reviewed studies, excluding a few outliers, accidents generally accounted for 5-13% of deaths, udder/teat disorders accounted for 8-25%, metabolic disorders accounted for 8-18% and unknown reasons accounted for 16-46% (Thomsen and Hue, 2006). In recent studies, the locomotor disorder was the most prevalent cause of on-farm mortality (USDA, 2007; McConnel et al., 2009; Thomsen et al., 2012). The proportion of deaths classified as "unknown" has been reduced considerably to < 5% (McConnel et al., 2009; Thomsen et. al., 2012). At the farm, the cause of death is primarily established by the owner or veterinarian's perception that sometimes does not reflect the true pathology leading to death; therefore a necropsy examination could provide valuable information about causes of death (McConnel et al., 2009, 2010; Thomsen et al., 2012). In general, for about 50% of the cases, farmers and necropsy agreed about the cause of death. To make necropsy examination practical, it should be performed only in cases where no obvious cause of death could be identified (McConnel et al., 2010; Thomsen et al., 2012). It would help the farmers to detect the flaws in accurately identifying and managing sick cows and thus help prevent future deaths.

Role of regulations on cow mortality

A legislative change in the United States at the end of December 2003 requiring euthanasia of downer cows to prohibit use in human food chain (USDA, 2003) caused a spike in mortality rate (Miller et al., 2008). Similarly, a change in regulations at slaughter (European Union regulation number 854/2004), only allowing healthy animals, was implemented in 2006 in Europe and may explain some of the increased risk for on-farm euthanasia there (Alvasen et al., 2012). Likewise, increased mortality rates in 2004 in Ireland have been suggested the result of revised rules for slaughter of cattle post BSE and also fitness to transport regulations (Maher et al., 2008). Although regulatory changes during last decade in different countries might have caused a spike in the mortality rate, they did not necessarily change the mortality trends as mortality rates were on the rise well before such legislative changes and it could be speculated that shifts in how cows are managed, genetic changes, or a combination of genetics and management have contributed to more cow deaths (Dechow et al., 2012).

The fundamental step in solving any problem could be acknowledging the importance of the issue. The recognition of the rising levels of mortality in dairy cows as a problem could be the first step in resolving this issue (McConnel et. al, 2010). The current study aimed to describe on-farm mortality in DHIA Midwest dairy cows. In one chapter, the mortality patterns in Midwest dairy herds have been presented and in the other chapter, the cow and herd level risk factors for cow mortality have been identified and their effects were quantified.

Table 1: Mortality as a percent of total culls (Reported in literature)

Country of study	Study period	Mortality (% of total culls)	Ranking (among culling reasons)	Authors
USA	2000-06	20.6	1st	Pinedo et al. (2010)
USA	1998	14.8	3rd	Smith et al. (2000)
USA	1995	11.3	4th	Bascom and Young (1998)
USA	1993-99	10.6	5th	Hadley et al. (2006)
USA	1994-95	9.3	5th	Ruegg et al. (1998)
USA	1981-85	6.2	>5th	Milian-Suazo et al., (1988)
USA	1965	4.5	>5th	Meadows, C. E. (1968)
USA	1960-61	5.8	>5th	O'Bleness and Van Vleck (1962)
USA	1958-63	2.9	>5th	White and Nichols (1965)
USA	1932-49	5.0	>5th	Asdell (1951)
USA	1930-35	6.6	> 5th	Seath , D.M. (1940)
Australia	1968-69	7.1	7th	Amiel and Moodie, (1973)
Canada	1990-93	1.5	>5th	Etherington et al. (1996)
Canada	1979-81	7.9	5th	Dohoo and Martin (1984)
Canada	1967-68	9.4		Burnside et al (1971)
UK	1990-92	7.6	4th	Esslemont and Kossaibati, (1997)
UK	1957-60	3.8	>5th	O'Connor and Hodges (1963)
France	2005-06	17.7		Raboisson et al. (2011)
France	1988-94	3.8	>5th	Seegers et al. (1998)
Ireland	1996	5.4		Leonard et al. (2001)

CHAPTER 2

DAIRY COW MORTALITY PATTERNS IN MIDWEST DHIA HERDS

The aim of this study was to describe the mortality patterns among cows in Midwest dairy herds. Approximately 5.9 million lactation records for cows from 10 Midwest states that calved between January 2006 and December 2010 were used. The overall cow level mortality rate was 6.4 per 100 cow-years and it increased from 5.9 in 2006 to 6.8 in 2010. Mortality rate was highest (21%) in early lactation (≤ 40 days in milk) and lowest in mid (100-199 days) to late lactation (200-305 days) with mortality rates of 3.5 and 3.6 %, respectively. The rate of mortality increased almost linearly with increasing parity. The rate was lowest in cows with parity 1 (3.5%) and highest (13.6%) in parity ≥5. In winter rate of mortality was highest (6.8%) followed by summer (6.6%). Spring and fall had similar mortality rates (6.1%). The observed average herd level mortality rate for the years 2006 to 2010 was 5.6±4.9% (mean ± SD). The yearly herd level mortality increased from 5.8±0.07% (mean ± SE) in 2006 to 6.6 ± 0.07 in 2010. Smaller herds (20 to 49 cow-years) had lower mortality rate (5.1±0.05%) than larger herds (≥ 500 cow-years) where mortality rate was 7.1±0.13. Herds with higher live culling rate (≥ 32.5%) had lower mortality (5.0±0.06%) than herds with lower live culling rate (≤ 16%) with a mortality rate of 5.8±0.07%. Herds with higher 305ME milk yield (≥ 11,364 kg) had lower mortality (5.1±0.05%) than herds with lower 305ME milk yield (< 7,727 kg) with mortality rate of 6.2±0.08. The overall yearly culling rate for the period of 2006 to 2010 was 33.3%. The yearly culling rate significantly increased from 30.3±0.21% (mean ± SE) in 2006 to 37.1±0.22% in 2010. The culling rate for smaller

herds (20 to 49 cow-years) was not different than the larger herds (≥500 cow-years) with the values of 30.3±0.16% and 30.8±0.40%, respectively. However smaller herds had significantly higher live culling rate (25.1±0.15%) than the larger herds (23.4±0.38%). Herds with different levels of milk yield had similar yearly culling rates; however, herds with high 305ME milk yield (≥ 11,364 kg) had significantly higher (25.6±0.21%) live culling rate than those of lower milk yield (< 7,727 kg) with the live culling rate of 21.8±0.2%. The frequency distribution of culling indicated that the primary reason of leaving the herd was cow died on farm (19.4% of total culls), followed by reproduction (14.6%), injuries and other (14.0%), low production (12.3%) and mastitis (10.5%). Increasing trends of mortality and culling over time suggest possibly compromised cow welfare.

Key words: cow mortality, culling, patterns

Introduction

On-farm dairy cow mortality is becoming a significant issue in the US dairy industry. Cow mortality has an important impact on dairy farm profitability and cow welfare (Thomsen et al., 2004). An increase in mortality among a group of dairy cows indicates suboptimal health and compromised welfare (suffering before death). Therefore mortality can be considered an important measure of animal welfare (Thomsen and Houe, 2006).

The normal or acceptable levels for dairy cow mortality have not yet been set. However, the extent of change in mortality rates among a certain population of dairy animals over time can tell whether the mortality is increasing or not. Also the comparison of different production systems and a prevalent range in mortality rates among dairy operations can give an idea about the minimum and maximum levels of mortality. McConnel et al. (2008) categorized herds into three groups on the basis of herd level mortality and described mortality rate of < 2.5% as low, 2.6 to 6.25% as medium and > 6.25% as high. The reported mortality rates were comparatively lower in older studies. Asdell (1951) studied the culling patterns in DHIA dairy herds from 17 states for the period of 1932 to 1949 by looking at 2,792,188 cows and reported that mortality was 1.1% of total cows. Dohoo et al. (1984) reported mortality rate of 1.5% per lactation among 2,875 lactation records of 38 Canadian Holstein herds during 1979 to 1981. Milian Suazo et al. (1988) reported mortality risk of 1.2% per cow lactation among 34 herds in New York State. Gardner et al. (1990) reported 2% mortality rate among 43 Californian dairy herds with a mean herd size of 373 cows.

Recent studies indicated that mortality risk has increased over time. Miller et al. (2008) reported 1.64% increase in mortality from 1995 to 2005 for the US national data set. The mortality in US dairy cows was 3.8% in 1996, 4.8% in 2004, and 5.7% in 2007 (USDA, 2007). Similarly, the mortality risk among Danish dairy cows has increased from 2% in 1990 to 3.5% in 1999 (Thomsen et al., 2004) and up to 5% in 2005 (Thomsen and Sorensen, 2008). This is further supported by the fact that reported mortality rates are quite high in recently published studies as compared to older ones. Smith et al. (2000) analyzed the DHIA records for the year 1998 and found that for the northern states of the US the mortality was 5.9%. Stone et al. (2006) reported a yearly mortality rate of 8.1% in 20 New York dairy herds. Miller et al. (2008) reported that death frequency was 5.7% per cow for the period of 1995 to 2005. A recent study done on 2,054 DHIA herds from 38 states indicated 6.6% mortality rate in cows that calved from 2001 to 2006 (Pinedo et al., 2010).

During the last 10 to 15 years, mortality risk has not only increased but also its ranking in culling reasons has been changed to a considerable extent. Bascom and Young (1998) reported mortality at 4th in ranking for reasons of culling (13% of total culls). Smith et al. (2000) analyzed the DHIA records for the year 1998 and found that for the northern states of the US, mortality was at 3rd (14.8% of total culls) in ranking for reasons of cows leaving the herd, whereas mortality was at the 1st in ranking for reasons of culling (20.6% of total culls) reported by Pinedo et al. (2010). This scenario increases the concerns related to compromised cow welfare during recent years.

The objective of this observational study was to describe the recent patterns of mortality in Midwest DHIA dairy herds in relation to time, parity, season, lactation stage, and different herd characteristics.

Materials and Methods

Data

The lactation records of DHIA herds from 10 Upper Midwest states were obtained from Dairy Records Management Systems (Raleigh, NC). The states included were Minnesota, Wisconsin, Illinois, Iowa, Indiana, Michigan, Ohio, Nebraska, North Dakota, and South Dakota. A total of 5.9 million records of cows that calved between January 1, 2006 and December 31, 2010 were used. The data contained information for cows on current and previous lactations including herd code, cow registration number, breed, calving date, parity, variables related to milk yield and composition, breeding information, date of removal from the herd, and removal code. Different herd and cow level parameters were estimated using lactation data.

Event of Interest

Event of interest was lactation ended due to on-farm death reported by DHIA record. In the records, the variable called Condition Affecting Record (CAR) indicated cow removal code. The CAR with termination code 6 indicated that lactation ended as died or euthanized on farm. Thus the event of mortality was expressed as 0 (cow entered into next lactation or left the herd due to reasons other than death) or 1 (died during lactation). The follow-up time for individual lactation as number of cow-days was estimated to calculate mortality rates. Follow-up time started at calving and ended till next calving or removal from the herd.

Mortality Rates

The mortality rates were calculated as number of cows that died during a time period divided by the total number of cow-years at risk during that duration. The number of cow-years was calculated by adding all the cow-days at the farm during a specific time period divided by 365.25 days (cow days were divided by 365.25 to convert cow-days at risk to cow-years at risk, 0.25 was added to account for leap year). A cow on a dairy farm for one day was considered as one cow-day (Raboisson et al., 2011; Pinedo et al., 2010; Fetrow et al., 2006).

The mortality rates for year, parity, lactation stage, and season were calculated. Parity was categorized into 1, 2, 3, 4, and ≥ 5. Season was divided into four categories: spring (March to May), summer (June to August), fall (September to November) and winter (December to February). Herds were divided on the basis of herd size and herd 305ME milk yield. Herd size was expressed into five categories: 20 to 49 cow-years, 50 to 99, 100 to 199, 200 to 499 and ≥ 500. Herd average 305ME milk yield was expressed into four groups: ≥ 11,364 kg, ≥ 9,546 to < 11,364 kg, ≥ 7,727 to < 9,546 kg and < 7,727 kg. Herds were also divided into quartiles on the basis of annual live culling and live culling in ≤ 40 days in milk (DIM).

Statistical Analysis

Data were analyzed using SAS (version 9.2; SAS Institute Inc., Cary, NC). For descriptive analysis of data, the frequency distribution of lactation records and herds by state, size, and production level was obtained using Proc Freq procedure. The range of herd level mortality rates was estimated by Proc Univariate procedure. The effect of year, herd size, milk yield and live culling rate on herd level mortality rate was analyzed using Proc GLM. The same procedure was used to analyze the effect of year, herd size and milk production level on culling rates. No interaction terms were added to models both for mortality rate and for culling rates.

Results and Discussion

Dataset characteristics

A total of 5,880,840 lactation records from 7,188 herds were available for analysis. Majority of the herds were from Minnesota (34.3%) followed by Ohio (12.3%), Wisconsin (12.1%), Iowa (12.1%), and Michigan (11.2%) as shown in Table 1. The average herd size was 140±266 (mean ± SD). The frequency of herd size is shown in Table 1. Herds with herd size 50 to 99 cow-years were highest in number (38% of total herds) followed by herd size 20-49 (27%), 100-199 (21%) and 200-499 (10%). Larger herds with herd size 500 or greater were only 4% of total herds in this dataset. The herds were also divided on the basis of average yearly 305ME milk yield. The frequency of herds with milk production ≥ 9,546 kg to < 11,364 kg was highest (44.5% of total herds) followed by herds with milk yield level ≥ 7,727 to < 9,546 kg (28.5%) and herds with milk production level ≥ 1,1364 (26.9%), as shown in Table 1. The lactation records for parity 4 or greater were relatively small (18%) as compared to parity 1 (37.5%; Table 2). Pinedo et al. (2010) used similar data; however, they mainly focused on states primarily east of Mississippi river and also they did not include herds with herd size < 100 cows. The current dataset excluded only herds with herd size < 20 cow-years. Smith et al. (2000) used DHIA dataset that was mainly based on herd summary records for the year 1998.

Mortality statistics

The overall mortality rate for the period 2006 to 2010 was 6.4% per 100 cow-years. On herd level basis, the mean mortality rate was 5.2±0.03% (mean ± SE). Mortality rate in our study was in close agreement with the recent studies and was higher than the studies published earlier than 2000. Burow et al. (2011) reported a mean annual mortality rate of 5.6% in 391 Danish dairy herds. Raboisson et al. (2011) studied the herd level and contextual factors influencing the dairy cow mortality in France and reported approximately 3.8% mortality rate. The average yearly herd size in their study was 38.2 cow-years with a range of 5.1 to 421.1 cow-years and also pasture grazing is common in France's dairy operations. Grazing is considered a more welfare friendly system than confinement (Burow et al., 2011). Dairy operations in US are generally more of intensive type with little or no pasture grazing. Pinedo et al. (2010) studied approximately 3.6 million lactation records from 2,054 US dairy herds primarily east of Mississippi river with herd size greater than 100 cows and reported a yearly mortality rate of 6.6% for the period of 2001 to 2006. Mortality rate in our study was slightly lower than Pinedo et al.

(2010) possibly because we included herds with < 100 cow-years and their study excluded the smaller herds (herds size < 100), and smaller herds tended to have lower mortality.

There was an increase in cow level mortality rate from 5.9% in 2006 to 6.8% in 2010 (Table 2). Herd level mortality rates also showed the same increasing trend as that of cow level mortality i.e. increased from 5.8±0.07% (mean ± SE) in 2006 to 6.6±0.07% in 2010 (P<0.001) as shown in Table 3. Increase in mortality over time has been reported previously. Miller et al. (2008) reported 1.64 percentage unit increases in mortality from 1995 to 2005 using a US national dataset. Similarly the mortality risk among Danish dairy cows increased from 2% in 1990 to 3.5% in 1999 (Thomsen et al., 2004) and up to 5% in 2005 (Thomsen and Sorensen, 2008). Likewise the mortality increased from 1.2% per 100 cow-years during 1989-1995 to 3.8% in 2005 in France (Seegers et.al., 1998; Raboisson et al., 2011). As the increase in mortality over time is being reported consistently in recent studies, it indicates that mortality in dairy cows is becoming a serious problem and more attention is needed to address this issue.

The minimum and maximum annual herd level mortality rate was 0 and 95.2% respectively. Herds with 0% mortality were about 10% of total herds in the study. Herds with mortality rate 10% or higher were in the 85th percentile and above (Table 4). Only five herds had mortality rate greater than 50%. The herds with mortality rates above 50% might have faced some fatal disease, disaster like fire, or they might have to euthanize large number of animals because of certain diseases in the herd. Alvason et al. (2012) reported that Swedish farms with certain diseases in the herd (e.g., *Salmonella*) are forced to euthanize the whole herd or large groups of animals. The range in herd level mortality rates was in agreement with Raboisson et al. (2011), who reported a range of mortality from 0 to 98.4%. The proportion of herds with zero mortality was comparatively lower than the proportion reported by Raboisson et al. (2011) where about 33% of herds had zero mortality. Other studies also reported a high proportion of herds with zero mortality. Faye and Perochon (1995) found 31% of herds with zero mortality among 47 herds in Brittany. Menzies et al. (1995) found 18.2% of herds with no mortality in 1,069 dairy herds in Northern Ireland and Thomsen et al. (2006) reported 26.9% out of 6,839 Danish dairy herds with zero percent mortality. The proportion of herds with higher mortality (≥10%) was in close agreement to what has been reported by Raboisson et al. (2011) where they found that in 90th percentile and above the herds had mortality rate of about 10%. This range of herd level mortality from 0% to >10% indicates a margin of improvement for lowering mortality rates.

Mortality was quite high (21%) in early lactation (≤ 40 days in milk) as compared to mid (100-199 days in milk) and late lactation (200-305 days in milk) where mortality rates were 3.5 and 3.6% respectively (Table 2). Figure 1 shows the frequency distribution of mortality by first the 40 days after calving. It is evident from the graph that the proportion of deaths is even higher in first 10 to 15 days after calving. The highest mortality rate in early days after calving was in agreement with previous studies. Raboisson et al. (2011) found that approximately 35 and 55% of the deaths occurred during the first 30 and 100 days of lactation, respectively. Pinedo et al. (2010) reported that during the first 100 days after calving mortality was the primary reported cause of leaving the herd. They found that the proportion of cows died among the total culled cows decreased from 57 to 22 % from 1 to 100 days of calving. Miller et al (2008) reported that the death frequency was highest (17.3%) in early lactation (≤ 45 days after calving) followed by 46 to 90 days after calving (10.1%), 91 to 150 days after calving (8.5%), 150 to 250 days after calving (6.5%) and ≥ 251 days after calving (0.9%).Similarly, the high death rate in early lactation has been reported in other studies (Milian-Suazo et al., 1988; Faye and Perochon, 1995; Menzies et al., 1995; Thomsen et al., 2004; Hadley et al., 2006; Dechow and Goodling, 2008).

The high mortality in early lactation could easily be explained by the findings of Shanks et al. (1981), Dohoo et al. (1983), and Markusfeld (1993) who reported that the period before and after calving is a high-risk period for many diseases. During this period a cow undergoes tremendous metabolic and endocrine changes related to parturition and the onset of lactation (Drackley et al., 2001). If the homeostatic mechanisms of the cow do not act effectively to respond to the changes in the body, disorders such as milk fever or clinical hypocalcaemia, ketosis, retained fetal membranes, metritis, mastitis, and displacement of the abomasum may occur (Grummer, 1995; Goff and Horst, 1997). These diseases affect cows within two weeks after calving (Drackley, 1999). Some diseases that become clinically apparent in later stage of lactation, such as laminitis, ovarian cysts, endometritis and anestrus are related to the early postpartum (Goff and Horst, 1997). The high occurrence of locomotor disorder in first 3 months of lactation has been reported by Green et al. (2002). Shanks et al. (1981) also found that health costs were highest during the first 30 days after calving and suggested that most disorders were associated with initiation of the lactation rather than the period of peak daily milk production. Therefore, this early period after calving is a high risk period of developing diseases related to the metabolic challenges of parturition and the beginning of lactation (Melendez and Risco, 2005). The association of mortality with health disorders during transition period has been investigated by Thomsen et al. (2004) who reported that the primary causes of on-farm mortality were related to those diseases which are common during periparturient period, e.g. milk fever, left- and right-displaced abomasum, mastitis caused by *E. coli*, calving disorders and locomotor disorders. These reports suggest that there is still an opportunity for better management to reduce problems related to onset of lactation. By reducing the periparturient problems with high quality management, mortality can be reduced.

Mortality rate increased with parity from 3.5% in parity 1 to 8.3% in parity 3 (Table 2). Similar findings have been reported earlier (Miller et al., 2008; Pinedo et al., 2010). Considering the cow mortality only in early lactation (≤40 days in milk), the rate was much higher in parity 3 cows (29.1%) than parity 1 (9.7 %) and parity 2 cows (14.0 %) and it was even higher in older cows (Table 2). This indicated that older cows were at higher risk in early lactation than younger cows.

Mortality rate was highest in winter (6.8%) followed by summer (6.6%) and the rate was almost the same for spring and fall at 6.1% each (Table 2). Pinedo et al. (2010) reported that highest mortality was in spring (7.8%) followed by summer (6.9%), winter (6.5%) and fall (5.5%). This difference could be due to the difference in categorizing months into four seasons. Our findings were in partial agreement with Miller et al. (2008) who reported that mortality was highest in summer months. The high mortality in winter months in this study could be explained because of increased accidents related to ice formation during winter or because of generally severe winter conditions.

Herd size had significant association with herd level mortality rates. The smaller herds (20 to 49 cow-years) had lower mortality (5.1±0.05%, mean ± SE) than the larger herds (≥ 500 cow-years, 7.1±0.13%) as shown in Table 3. This was in agreement with previous studies. Pinedo et al. (2010) reported mortality rate of 5.8% for herds of 100 to 200 cows and 9.6% for herds > 3,000 cows. Similar findings have been reported in some other studies indicating a higher mortality in larger herds (Nørgaard et al., 1999; Smith et al., 2000; Thomsen et al., 2006; McConnel et al., 2008; Raboisson et al., 2011).

Herds with higher 305ME milk yield (milk yield ≥ 11,364 kg) had lower mortality (5.10 ± 0.05%) than herds with lower 305ME milk yield (milk yield < 7,727 kg 6.2±0.08%) as shown in table 3. This was in agreement with Smith et al. (2000) who reported an increase in mortality from 5.9 % to 7.1% and 7.7% for herds with milk yield > 9,072 kg, 7,258 to 9,072 kg and < 7,258 kg, respectively.

When the herds were divided into quartiles on the basis of yearly live culling rate, it was found that the herds with highest live culling rate (4^{th} quartile: live culling > 35.2%) had lower mortality rate (5.0±0.06%) than the herds with lowest live culling rate (1^{st} quartile: live culling ≤ 16%) which had herd level mortality of 5.8±0.07% (Table 3). This negative association between average live culling and mortality was in agreement with previous studies where they found that with the increase in live culling rate the mortality rates decreased (Pinedo et al., 2010; Raboisson et al., 2011). However, when herds were ranked into quartiles on the basis of live culling in ≤ 40 days, mortality rate was lower (5.0 ± 0.06%) in herds with lowest live culling in ≤ 40 days (1st quartile: live culling ≤ 0.8%) than herds with highest live culling in early lactation (4th quartile: live culling > 5.5%) which had mortality 6.2 ± 0.06%. The increased risk of live culling in early lactation is associated with increased transition cow problems (Beaudeau et al., 1994; Geishauser et al., 1998; Gröhn et al., 1998; Seegers et.al., 1998; Rajala-Schultz and Gröhn, 1999). The herds with high incidence of such problems might indicate poor transition cow management thereby increasing the risk of mortality in such herds. However, McConnel et al. (2008) reported findings contrary to this study where they found that the herds with a low percentage of culled cows in first 50 days after calving (% of cows culled ≤ 2.0) were 1.97 times more likely to have a greater level of mortality than the herds with a moderate level (2.1 to 20.8%) of cows that were culled in less than 50 days after calving. They speculated that the increased mortality in such herds might be due to the inability of the producers to identify and remove the severely diseased animals from the herd on time.

Culling statistics

The overall annual herd level culling rate for the period 2006 to 2010 was 29.7 % ± 0.08 (mean ± SE) and live culling rate (excluding the culls due to death) was 24.4 % ± 0.07. These rates were in close agreement with the previously reported range of culling rates. Raboisson et al. (2011) reported 21.5 % yearly live culling rate among dairy cows in France for the year 2005 and 2006. Pinedo et al. (2010) reported 25.1 % live culling rate in which they did not include the disposal code dairy purpose in culling estimation. They considered culling as removal from the herd with any disposal code other than dairy purposes as the cows sold for dairy purpose remain in the production cycle on other dairy operation and might not be considered as culled cow (Fetrow et al., 2006). Hadley et al. (2006) reported an average annual culling rate ranging from 33 to 39 % for Midwest states. Smith et al. (2000) reported an average culling rate of about 35.1% for northern states of USA. Quaiffe (2002) reported that the average annual culling rate for Upper Midwest DHIA herds in 2001 was 38%. Ruegg et al. (1998) reported 26.7% culling rate on lactation basis in 32 commercial Holstein dairy herds in Upper Midwest states. The variation in the reported culling rates could be due to different method of calculating culling rate (Smith et al., 2000). Some studies did not include mortality in the culling rate estimation (Ruegg et al., 1998), and some did not include the disposals for dairy purpose in culling rate estimation (Pinedo et al., 2010). Changes in herd size due to season or expansion purposes might also be related to culling rate variations (Ruegg et al., 1998).

The effect of year, herd size and milk yield on culling dynamics is shown in Table 5. Herd level culling rate increased from 30.3 ± 0.21% in 2006 to 37.1 ± 0.22 %in 2010. Herd size did not have much effect on total culling in this dataset. Smaller herds (herd size = 20 to 49 cow-years) had almost similar culling rate (30.3±0.16%) than larger herds (herd size ≥ 500 cow-years) where the rate was 30.8±0.40% (Table 5). However, Smith et al. (2000) and Pinedo et al. (2010) reported an increase in culling rate with the increase in herd size. The non-significant effect of herd size on culling in our study could be due to unknown confounding factors. Herds with higher milk yield (305ME milk yield ≥ 11,363 kg) had higher culling rate (30.7±0.16%) compared to the herds with lower milk yield (305ME milk yield < 7,727 kg) with culling rate 28.2±0.27%. These results were in close agreement with the findings of Smith et al. (2000). They reported culling rate as 34.2%, 35.7% and 36.0% for herds with low (< 7,258 kg), medium (7,258 – 9,072 kg) and high (> 9,072 kg) milk production. Similarly Hadley et al. (2006) and Pinedo et al. (2010) reported positive association between milk yield and involuntary culling. Batra et al. (1971) also reported an increase in percent of cows culled with the increase in herd milk production level irrespective of herd size.

Live annual culling rate (culling rate excluding culls due to death) had negative association with herd size. Smaller herds (herd size = 20 to 49 cow-years) had significantly higher live culling rate (25.1 ± 0.15 %) than the larger herds (herd size = ≥ 500) with live culling rate of 23.4 ± 0.38 %. Lower live culling and high mortality, as mentioned before, in larger herds might be the consequence of reduced time spent on individual cows thereby decreasing the chances of workers to identify and treat or remove the problem cows from the herd and letting them to die on farm. However, herds with high milk yield (305ME milk yield ≥ 11,363 kg) had higher live culling (25.6 ± 0.21 %) than herds with lower milk yield (305ME milk yield < 7,258 kg) where live culling rate was 21.8±0.21% (Table 5). Live culling in ≤ 40 days after calving was lower (3.4±0.05%) in smaller herds (herd size, 20 to 49 cow-years) than the larger herds (herd size, ≥ 500) where live culling in ≤ 40 days was 4.1±0.12 % (Table 5). Relatively greater culling in early lactation for larger herds might be the result of increased incidence of transition cow problems. High producing herds had higher live culling in ≤ 40 days than the low producing herds (Table 5). Increased levels of yearly live culling and live culling in ≤ 40 days in high producing herds might indicate the prompt decision making attitude of the producers to cull the problem cows instead of treating them for longer times. These high culling rates seemed a management strategy to maintain herd production up to a certain level because the diseased cows significantly produce low quantities of milk (Dohoo and Martin, 1984; Østergaard and Gröhn, 1999). The replacement heifers with higher genetic potential entering the herds each year might also explain the high levels of production in such herds.

The frequency distribution of reasons why cows left the herd is shown in Table 6. The primary reason for leaving the herd was that the cow died on farm (19.4% of total culls), followed by reproduction (14.6%), injuries and other (14.0%), low production (12.3%) and mastitis (10.5%). The results of frequency distribution for reasons of culling are in agreement with the findings reported by Pinedo et al. (2010). In their data the primary reason for cow removal was death (20.6% of total culling), followed by reproduction (17.7%), injury/other (14.3%) and low production and mastitis (both 12.1%). Our findings are in partial agreement with older studies except that cow death was at that time a lesser reason for culling. Hadley et al. (2006) analyzed the DHIA records from 1993 to 1999 and reported that injury or others (26.9% of total culls) was the primary reason for culling followed by reproduction (18.9%), low production(12.8%), mastitis (12.1%) and then mortality (10.6%). Smith et al (2000) analyzed the DHIA records for the year 1998 and found that for the northern states of USA , injuries/others was the most common reason for culling (25.8% of total culls) followed by reproduction (17.1%), death (14.8%) and mastitis (11.9%). Meadows (1968) analyzed the disposal of 27,611 cows during 1965 for Michigan DHIA herds and found that low production was the primary reason for culling (52.1% of total culls) followed by sterility (16.6%), dairy purpose (9.2%), injuries (6.7%), mastitis (5.5%) and death (4.5%). The increase in ranking of mortality over time among the reasons for cows leaving the herd may indicate that welfare of dairy animals has been compromised during the last few decades.

Conclusions

Mortality among cows of Midwest DHIA dairy herds increased from 2006 to 2010. More cows died in early lactation and the mortality rate increased with increasing parity. In winter and summer months, more cows died compared to spring and fall. Mortality rate was lower in smaller herds and higher in larger herds. Range of mortality rates for herds could be used to set the realistic standards for cow mortality in dairy herds. Herds with higher live culling rate had lower mortality rate. Mortality rates were lower in high producing herds. Mortality was the main reason for cows leaving the herds.

Table 1: Distribution of herds by state, herd size and milk yield

Category	% of total herds
State (n= 7,188)	
Minnesota	34.3
Wisconsin	12.1
Ohio	12.3
Iowa	12.2
Michigan	11.2
Illinois	6.7
Indiana	6.1
South Dakota	2.3
Nebraska	2.2
North Dakota	0.7
Herd size, no. of cow-years[1] (n=7,188)	
20-49	
50-99	26.6
100-199	38.0
200-499	21.0
≥ 500	10.0
	4.0
Herd 305ME[2] milk yield, kg (n=7,064)	
≥11,364	
≥ 95,46 to < 11,364	26.9
≥ 7,727 to < 9,546	44.5
< 7,727	28.5
	15.8

[1]A cow-year means, one cow that stayed in the herd for one year.
[2]305ME = 305-d mature equivalent.

Table 2: Distribution of lactation records by parity

Parity	% of total lactation records (n=5.9 million)
1	37.5
2	26.9
3	17.3
4	9.7
≥5	8.5

Table 3: Cow level mortality rates by year, season, lactation stage and parity in Midwest DHIA dairy herds (no. of lactations = 5.9 million)

Variable	Mortality rate % (per 100 cow-years)
Overall mortality	6.4
Year	
2006	5.9
2007	6.2
2008	6.7
2009	6.4
2010	6.8
Season	
March – May	6.1
June – August	6.6
Sep – November	6.1
Dec – February	6.8
Lactation stage, days in milk	
≤ 40	20.5
41 – 99	5.0
100 – 199	3.5
200 – 305	3.6
≥ 306	4.6
Parity	
1	3.5
2	5.2
3	8.5
4	11.0
≥5	13.6
Mortality rate in ≤ 40 days by Parity	
1	9.7
2	14.0
3	29.1
4	40.3
≥5	51.6

Table 4: Herd level mortality rates by year, herd size, milk yield and culling for Midwest DHIA herds during 2006 to 2010 (no. of observation =35,823).

Variable	(MR, %) (LS Mean ± SE[1])
Overall, unadjusted	5.2 ± 0.03
Year	
06	5.8[a] ±0.07
07	6.1[a] ±0.06
08	6.4[bd]±0.06
09	6.3[bc]±0.06
10	6.6[d] ±0.07
Herd size, cow-years[2]	
20 - 49	5.1[a]±0.05
50 - 99	5.1[a]±0.04
100 - 199	5.6[b]±0.06
200 - 499	6.3[c]±0.08
≥ 500	7.1[d]±0.13
Herd 305ME[3] milk yield, kg	
≥11,364	5.1[a]±0.05
≥ 9,546 to < 11,364	5.8[b]± 0.05
≥ 7,727 to < 9,546	6.3[c]±0.06
< 7,727	6.2[c]±0.08
Annual live culling rate,%	5.8[a]±0.07
≤ 16	6.7[b]±0.06
16 to 24.7	5.8[a]±0.06
24.7 to 32.5	5.0[c]±0.06
> 32.5	
Live culling rate ≤ 40 d in milk,%	
≤ 0.8	5.0[a]±0.06
0.9 to 2.9	6.1[b]±0.06
3.0 to 5.4	6.0[b]±0.06
> 5.5	6.2[b]±0.06

[1]Least square means ± standard error

[2]A cow-year means one cow that stayed in the herd for one year

[3]305ME = 305-d mature equivalent.

[a,b,c,d] Means within a column with the same superscripts do not differ for each variable (*P* < 0.05).

Table 5: Range of herd level mortality rates for Midwest DHIA herds during 2006 to 2010 (no. of observation=37,055).

Quartile	Percentile	Mortality rate, %
Minimum	0	0.0
	1	0.0
	5	0.0
	10	0.0
1st quarter	25	2.2
Median	50	4.8
3rd quarter	75	8.0
	85	10.0
	90	11.6
	99	22.0
Maximum	100	95.2

Table 6: Frequency distribution of culling with DHIA reported removal codes (n=1.62 million)

Reasons of culling	% of total culls
Mortality	19.4
Injuries and others	14.0
Reproductive problems	14.6
Low production	12.3
Mastitis	10.5
Dairy	9.3
Feet and leg	5.6
Disease	4.8
Udder problems	2.3
Not reported	7.2

Table 7: Herd level annual culling rates by year, herd size and milk yield for Midwest DHIA herds during 2006 to 2010 (no. of observation =359,563).

Variable	Total culling[1] (LS Means ± SE*) %	Live culling[2] (LS Means ± SE) %	Live culling ≤ 40 days (LS Means ± SE) %
Overall, unadjusted	29.7 ± 0.08	24.4 ± 0.07	.7 ± 0.023
Year			
06	30.3[a] ± 0.21	24.3[a] ± 0.20	3.8[ac] ± 0.06
07	32.0[b] ± 0.21	25.8[b] ± 0.19	3.6[b] ± 0.06
08	33.4[c] ± 0.20	26.9[c] ± 0.19	3.8[ab] ± 0.06
09	34.9[d] ± 0.21	28.4[d] ± 0.19	4.1[c] ± 0.06
10	37.1[e] ± 0.22	30.4[e] ± 0.20	4.5[d] ± 0.06
Herd size (cow-years)			
20 - 49	30.3[ac] ± 0.16	25.1[a] ± 0.15	3.4[a] ± 0.05
50 - 99	30.0[ac] ± 0.13	25.0[a] ± 0.13	3.7[b] ± 0.04
100 - 199	29.6[ab] ± 0.18	23.9[b] ± 0.17	3.8[bc] ± 0.05
200 - 499	29.1[b] ± 0.25	22.6[c] ± 0.24	3.7[ab] ± 0.08
≥ 500	30.8[c] ± 0.40	23.4[bc] ± 0.38	4.1[c] ± 0.12
Herd 305ME[3] milk yield, kg			
≥ 11,364	30.7[a] ± 0.16	25.6[a] ± 0.21	4.3[a] ± 0.04
≥ 9,546 to < 11,364	30.5[a] ± 0.14	24.7[b] ± 0.21	3.9[b] ± 0.04
≥ 7,727 to < 9,546	30.3[a] ± 0.19	23.9[c] ± 0.20	3.6[c] ± 0.05
< 7,727	28.2[b] ± 0.27	21.8[d] ± 0.21	3.2[d] ± 0.07

[1]Total culling includes culls due to all reported reasons
[2]Live culling excludes culls due to death
[3]305ME = 305-d mature equivalent.
[a,b,c,d,e]Means within a column with the same superscripts do not differ for each variable (*P* <0.05).

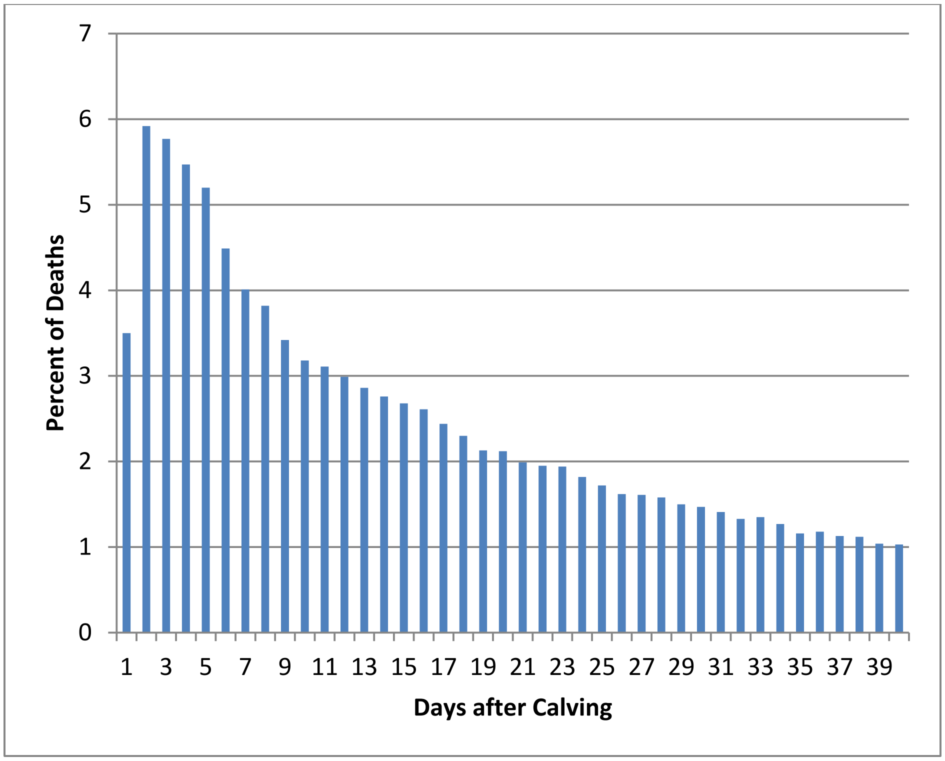

Figure 1: Distribution of deaths during the first 40 days after calving

CHAPTER 3

RISK FACTORS FOR MORTALITY IN MIDWEST DAIRY HERDS

Cow and herd level risk factors associated with on-farm mortality (euthanasia and death) in Upper-Midwest US dairy herds were investigated with lactation survival analysis. A total of 5,899,732 DHIA lactation records, from cows that calved from January 2006 to December 2010 from 10 Midwest states, were analyzed. The cow-level independent variables used in the models were 1st test day milk yield, fat to protein ratio, fat percentage, protein percentage, milk urea nitrogen, somatic cell score, body weight at calving, previous lactation dry period length, previous calving interval, season of calving, calving difficulty, calf sex, twinning, stillbirth, parity and breed. The herd-level variables included herd size, calving interval, somatic cell score, 305ME milk yield, and herd stillbirth percentage. The increased hazards of mortality were associated with higher fat to protein ratio (> 1.6 vs. 1-1.6), higher fat percent, lower milk protein percent, cows with male calves, cows carrying multiple calves, higher milk urea nitrogen, increasing parity, longer previous calving interval, higher 1st test day somatic cell score, increased calving difficulty score and breed (Holstein vs. others). The decreased hazards of mortality were associated with higher 1st test day milk yield, and higher milk protein. For herd level factors, increased mortality hazards were associated with increased herd size, increased percentage of stillbirths, higher somatic cell score and increased herd calving interval. Cows in herds with higher milk yield had lower mortality hazards. The results of current study indicate that first test day records especially those indicative of negative energy balance in cows could be helpful to identify animals at high risk of mortality. It was also noted that higher milk yield did not seem to have harmful effects on mortality. In addition, the association between herd level factors and mortality indicated that management quality could be an important factor in lowering on-farm mortality thereby improving cow welfare.

Key words: cow mortality, risk factors

Introduction

The percentage of on-farm mortality is one of the variables of routine herd data that is associated with animal welfare indicators (De Vries et al., 2011). A rise in on-farm mortality among cows indicates compromised cow welfare (Thomsen et al., 2004). On-farm mortality also causes economic losses, including value of animal, its replacement cost, the loss of milk production and the extra labor used for its care, treatment, and eventually carcass disposal (Thomson et al., 2006). Considering the impact of mortality on cow welfare and dairy farm profitability, the published studies related to mortality are still sparse (Thomsen and Sørensen, 2008; Raboisson et al., 2011).

Today's dairy cow is under great physiological stress of producing high amounts of milk and physical stress of increased herd size and mechanization. Nørgaard et al. (1999) investigated the impact of intensive production methods on animal welfare and found that increase in concentrate consumption, milk yield and herd size have contributed to increasing cow mortality. They interpreted the milk yield as an indicator of physiological stress and genetic improvement in milk yield. Weigel et al. (2003) reported that the risk of involuntary culling in high producing cows increased over time as compared to average cows. Miller et al. (2008) reported that death increased with lactation milk yield. High milk yield is genetically correlated with negative energy balance (Harrison et al., 1990). In early lactation, negative energy balance plays a vital role in metabolic disorders such as ketosis, fatty liver, displaced abomasum and locomotive disorders like laminitis (Baird, 1982; Goff and Horst, 1997; Collard et al., 2000). These metabolic disorders along with suppressed immune system in early lactation, coliform mastitis, clinical hypocalcaemia and calving difficulty increase the risk of death and culling in dairy cows (Dohoo and Martin, 1984; Milian-Suazo et al., 1989; Wenz et al., 2001), especially in early lactation (Miller et al., 2008; Hadley et al., 2006). However, Young (2002) found that mortality rate was lower in high producing cows (top 25%) than low producing cows (lowest 25%), indicating no manifestation of physiological stress due to higher milk yield. Similarly, Gröhn et al. (1998) reported that high producing cows were less likely to be culled than cows with mean milk yield on a particular test day. This was supported by Dechow and Goodling (2008), who suggested that the decline in productive life of cows was not because of genetic selection for higher milk production. Also Miller et al. (1994) reported that the selection for high milk yield did not necessarily decrease total survival rates of cows from birth through early lactation of primiparous cows. Therefore, despite the apparently lower genetic potential for survival in high producing cows as indicated by some studies, management quality may reduce the risk of mortality in such cows (Dematawewa and Berger, 1998; McConnel et al., 2008;).

Management strategies also have a significant impact on increased mortality. Free-stall barn with deep litter, use of summer grazing, and lower proportion of purchased cows were significantly associated with decreased odds of mortality (Thomson et al., 2006). Similarly, composition of total mix ration, early culling, sick cow treatment, calving interval, lameness and respiratory problems were associated with high mortality in dairy cows (McConnel et al., 2008). Thomson et al. (2006) reported that mortality decreased with the increased herd-level milk yield and with the decreased somatic cell count. Smith et al. (2000) reported that herds with high production level (> 9,072 kg) had lower mortality (5.6%) compared with herds of medium (7,258 to 9,072 kg) and low production level (<7,258 kg) with mortality 7.1 and 7.7%, respectively. To attain high milk yield and low somatic cell count a high quality management is needed (Pecsok et al., 1991; Sargeant et al., 1997; Barkema et al., 1999). This implies that good quality management can effectively lower the risk of mortality. The objective of this observational study was to further identify cow and herd level risk factors for mortality and to estimate the strength of association of these factors with on-farm cow mortality in Midwest US DHIA dairy herds.

Materials and Methods

Study Population

The lactation records of DHIA herds from 10 Upper Midwest states were obtained from Dairy Records Management Systems (DRMS; Raleigh, North Carolina). The states included were Minnesota, Wisconsin, Illinois, Iowa, Indiana, Michigan, Ohio, Nebraska, North Dakota, and South Dakota. A total of 5.9 million records of cows that calved between January 1, 2006 and December 31, 2010 were used. The dataset contained information for cows on current and previous lactations including herd code, cow registration number, breed, calving date, parity, variables related to milk yield and composition, breeding information, date of removal from the herd, and removal code. Different herd and cow level parameters were estimated using lactation data.

Dependent Variable

The dependent variable or event of interest was lactation ended due to on-farm death reported by DHIA record. In the dataset, the variable called Condition Affecting Record (CAR) indicated cow removal code. The CAR with termination code 6 indicated that lactation ended as died or euthanized on farm. Thus the event of mortality was expressed as "0" (cow entered into next lactation or left the herd due to reasons other than death) or "1" (died during lactation). For the purpose of time-to-event analysis for mortality, follow-up time for individual lactation as number of cow-days was estimated. Follow-up time started at calving and ended till next calving or removal from the herd.

The records which ended when cow exited herd by on-farm death were treated as uncensored (1) while all rest as censored (0).

Explanatory Variables

Different explanatory variables were estimated from lactation records. Cow-level explanatory variables included 1st test day milk yield, fat %, protein%, fat to protein ratio, somatic cell score, milk urea nitrogen, calving difficulty, calf sex, twinning, previous calving interval, previous lactation dry period length, parity, body weight at calving, breed, and season of calving. Herd level variables were, herd size, herd level stillbirth percentage, average calving interval, herd 305ME milk, and herd somatic cell score. The explanatory variables have been chosen to get an idea of management quality and herd characteristics. The selected variables were related to the main management areas: production, transition cow management, milking management, reproductive management, and cow and herd characteristics (Table 1).

The explanatory variables were categorized as follows: 1st test day milk yield (1stMY) was expressed as a relative value from the mean on herd year-season basis and was categorized into three levels, low = cows producing less than one standard deviations (1 SD) below the herd-year-season average [low < (mean - 1 SD)], medium = cows producing between 1 SD below and 1 SD above the herd-year-season average [medium = (mean ± 1 SD)], and high = cows producing above 1 SD of the herd-year-season average [high > (mean + 1 SD)]. Similarly, milk fat percentage (fat, %), and milk protein percentage (protein, %), were categorized into three classes as low, average, and high, on herd-year-season basis. Fat to protein ratio (FPR) was categorized into three groups: low

(FPR < 1), average (FPR = 1.0 to 1.6), and high (FPR > 1.6). The values of fat %, protein %, and FPR were not used in the analysis where days in milk were < 5, in order to exclude the transition milk period. Milk Urea Nitrogen (MUN) was expressed as a relative value from the mean on the herd year-season basis and was divided into three levels, low = MUN value of 6 point below the herd-year-season average [low < (mean - 6)], average = MUN between 6 point below and 6 point above the herd-year-season average [average = (mean ± 6)], and high = MUN value 6 points above the herd-year-season average [high > (mean + 6)]. The figure 6 was used to accommodate the normal range of MUN values with in the same group of cow (DRMS, 2012). Cow somatic cell score (SCS) was categorized into five categories based on DRMS classification: ≤ 3.0, 3.1 to 4.9, 5.0 to 5.9, 6.0 to 6.9 and ≥ 7.0 (DRMS, 2013). Calving difficulty was expressed into five categories: 1 with no problem at calving to 5 with extreme difficulty (DRMS, 2011). Calf sex was expressed as “male” or “female”. Twinning was expressed as “yes” (lactation started with calving more than one calf) and “no” (lactation started with calving one calf). Lactation started with stillbirth (stillbirth) was expressed in two categories,” yes” lactation started with stillbirth, and “no” lactation started with live calf. . Stillbirth was defined as death of a calf that occurs just prior to, during, or within 24 to 8 h of parturition (Philipsson et al., 1979). Previous lactation calving interval (PCI) was treated as a continuous variable in months. The records with calving interval ≤ 9 months were excluded from the analysis. Previous lactation dry period (PDP) was categorized into three groups, short (PDP < 30 days), medium (PDP =30 to 70 days), and long (PDP > 70 days). Body weight at calving (BW) was expressed as a relative value from the mean on parity basis and was categorized into three levels, low = cows with BW less than one standard deviations (1 SD) below the parity average [low < (mean - 1 SD)], medium = cows with BW between 1 SD below and 1 SD above the parity average [medium = (mean ± 1 SD)], and high = cows with BW above 1 SD of the parity average [high > (mean + 1 SD)]. Lactation number was categories into 5 classes, parity 1, 2, 3, 4, and parity ≥ 5. Season of calving was divided into four categories: spring (March to May), summer (June to August), fall (September to November) and winter (December to February). Breed category was divided into Holstein, Jersey, Brown Swiss, Ayrshire, Guernsey, Crossbred, and last category as all others. Herd level calving interval (HCI) was categorized into three classes, good (HCL=12 - 14 months), average (HCI= 15 - 16 months), longer (HCI > 16 months). Herd size was expressed into four categories, small (20 to 99 cow-years), medium (100 to 199 cow-years cow-years), medium large (200 to 499 cow-years), and large (≥ 500 cow-years). One cow-year means one cow that remains in the herd for one year. The records from herds with < 20 cow-years were excluded from analysis. Herd stillbirth percent (HSP) was expressed into three categories, low (HSP ≤ 5%), medium (HSP= 6 to 15%), and high (HSP > 25%). Herd average somatic cell score (HSCS) was categorized into five groups and was expressed as, low (HSCS ≤ 2), low medium (HSCS= 2.1 to 2.5), medium (HSCS = 2.6 to 3.0), medium high (HSCS= 3.1 to 3.5), and high (HSCS ≥ 3.6). Herd average 305ME milk yield (HMY) was expressed into four groups, high (HMY ≥ 11,364 kg), medium high (HMY ≥ 9,546 to 11,363 kg), medium low (HMY ≥ 7,727 to 9,545 kg), and low (HMY < 7,727 kg). The categories for herd milk yield, somatic cell score and calving interval were derived from the Minnesota DHI yardstick (MN-DHIA, 2011). Herd stillbirth percent, herd average somatic cell score, and herd average 305ME milk yield were taken as an indicator of herd management quality.

Statistical Analysis

To evaluate the association between mortality and different cow level and herd level risk factors, the Cox Proportional Hazards regression was used. The survival analysis was done by the PROC PHREG procedure of SAS (release 9.2; SAS Institute Inc., Cary, NC). First the univariate analysis was performed. The variables with ***P***-value ≤ 0.2 in univariate analysis were considered for inclusion in the multivariable model. The main Cox regression model was as follows:

Mortality Hazard = baseline hazard × exp (1^{st}MY + FPR + fat% + protein% + calf sex + parity + twinning + stillbirth + season + SCS + breed + BW + herd size + HCL + HMY + HSP + HSCS)

Where exp is the exponent function, 1^{st}MY is first test day milk yield, FPR is fat to protein ratio, SCS is somatic cell score, BW is the body weight at calving, HCL is the herd calving interval, HMY is the herd 305ME milk yield, HSP is the herd stillbirth percentage, and HSCS is the herd somatic cell score. The baseline hazard is an unspecified hazard in Cox regression models. In order to avoid the effect of collinearity between the explanatory variables, the related variables were not analyzed in the same model. As FPR was estimated from 1^{st} test day fat % and protein %, therefore their association with mortality was estimated in separate models. Similarly, association of stillbirth was estimated excluding herd stillbirth from the main model. Among the correlated variables, the one was used in the main model that had the better fit of the data shown by likelihood ratio statistics. The MUN values were available only for the year 2010 therefore model-2 was run to analyze the association of MUN with mortality. In model-2 MUN was added in main model. In order to assess the relationship of previous calving interval (PCI) and previous dry period (PDP) with mortality, model 3 was run. For model-3, the PCI and PDP were added in the main model. The PCI and PDP too were analyzed one by one in model 3 to avoid collinearity. The number of observations used in model-3 decreased more than half as compared to observations used in main model because model 3 did not include records from parity 1. The hazards ratios (HR) for explanatory variables along with 95% confidence interval (CI) are presented in Table 2.

Results and Discussion

I) Cow Level Risk Factors

Fat to protein ratio

Fat to protein ratio (FPR) showed a strong association with on farm mortality. Cows with high FPR (> 1.6) at 1st test day had 43% higher mortality hazards (HR: 1.43; CI: 1.41 - 1.45) than the cows with average FPR (1.0 to 1.6). The higher incidence of mortality among cows with high FPR (> 1.6) could be associated with the disorders related to energy deficit in early lactation as FPR of greater than 1.5 is an indicative of energy deficiency (Duffield et al., 1997; Heuer et al., 1999). This energy deficiency or negative energy balance predisposes the cows to various postpartum disorders such as retained placenta, metritis, endometritis, mastitis, displaced abomasum, and clinical ketosis (Ingvartsen and Andersen, 2000; Drackley et al., 2005). Heuer et al. (1999) reported that cows with FPR greater than 1.5 in early lactation had higher risk for ketosis, displaced abomasum, ovarian cyst, lameness, and mastitis. Toni et al. (2011) reported that FPR greater than 2.0 in early lactation was associated with an increase in postpartum diseases such as retained placenta, left-displaced abomasum, metritis and clinical endometritis. They further analyzed the lactation survival and found that the hazards of culling were significantly higher among cows with early postpartum FPR ≥ 2 than cows with FPR 1.0 to 1.5. Mortality accounted for 11% of total culls in their study.

Milk fat percentage

Both high and low milk fat % was associated with mortality. The cows with high fat % [> (mean+1 SD)] at 1st test day had 43% higher mortality hazards (HR: 1.43; CI: 1.36 – 1.40) than the cows with average fat % (mean ±1 SD) as shown in Table 2. High fat % is an indicative of subclinical and clinical ketosis (Duffield et al., 1997) and subclinical ketosis increases the risk of culling and mortality (Gröhn et al., 1998; Rayala-Schultz et al 1999).

Also, the cows with low fat % [< (mean-1SD)] had 14% more hazards of mortality compared to cows with average fat % at 1st test day (Table 2). Low milk fat has been associated with subacute ruminal acidosis (Nordlund et al., 1995). Early transition cows are at higher risk due to reduced absorptive capacity of the rumen (Dirksen et al., 1985), poorly adapted rumen flora, and the rapid introduction to high-energy dense diets (Mulligan et al, 2006). Subacute ruminal acidosis may leads to laminitis (Enemark et al., 2002, Kleen, 2004), and abomasal displacement (Olson, 1991) making such cows at high risk of being dead.

Milk protein percentage

Low milk protein percentage at 1st test day was significantly associated with mortality. Cows with low milk protein % [< (mean-1SD)] had 38% higher mortality hazards (HR: 1.38; CI: 1.36 – 1.40) than cows with average milk protein % (mean±1SD). Milk protein content reflects energy intake in lactating dairy cows (Coulon and Remond, 1991). Duchateau et al. (2005) reported that low milk-protein concentration (< 2.7%) was associated with a negative energy balance. The low levels of milk protein reflected deficiency of energy intake from diet (Sato, 1998). As the cows are already in negative energy balance during early lactation, the further decline in dietary energy might have aggravated the negative energy balance and thus predisposing the cows to different metabolic diseases thereby increasing the hazards of mortality for these cows.

However, high milk protein was protective for mortality in our study. Cows with high milk protein % [> (mean+1SD)] had 5% less mortality hazards than the cows with average milk protein % (mean±1SD) as shown in Table 2. Favorable effect of high milk protein on reproduction has been reported (Buckley, 2003; Duchateau et al., 2005) indicating better energy balance in early lactation. Better emery balance reduces the risk of metabolic disorders that could explain the lower mortality in such cows.

Milk Urea Nitrogen

Cows with elevated MUN values [> (mean+6)] at 1st test day had 14% higher mortality hazards (HR: 1.14; CI: 1.10 – 1.18) than cows with MUN values within normal range (mean±6). One of the common reasons of elevated MUN is excessive protein intake (Jonker et al., 1998; Nousiainen et al., 2004). Similarly, cows under negative energy balance tend to have slightly higher urea concentration in milk, which could be associated with the increase of body protein mobilization (Schepers and Meijer, 1998). The increased hazards of mortality among cows with elevated MUN could be due to increased energy deficit, as the excess protein intake could exacerbate the negative energy balance (Gou et al., 2004) because of the extra energy required to detoxify and excrete urea (Tyrrell et al., 1970; Butler, 1998). Low MUN was also associated with increased mortality in dairy cows (Table 2).

1st Test Day Milk Yield

Both high and low first test day milk yields were significantly associated with on farm mortality. Within herd, cows with high 1st MY [> (mean+1SD)] had 5% less hazards of mortality (HR: 0.95; CI: 0.94 – 0.96) than cows with average milk yield (mean±1SD; Table 2). These results are in agreement with previous studies. Pinedo et al. (2010) reported that the annualized mortality rate was lower (2.7%) in cows with cow-relative 305ME milk yield > 2,187 kg than the cows with cow-relative 305ME milk yield < -2,313 kg where annual mortality rate was 9.9%. Similarly, Hadley et al. (2006) reported that cows producing 45 kg more milk than average 305ME milk yield were 0.5 to1.7% less likely to be culled than the average producing cow. In contrast Miller et al.

(2008) found that death frequency increased 0.4% when the average milk yields per cow increased by 1,000 kg in Holsteins.

Although the genetic correlation between milk yield and cow survival are slightly negative and phenotypic correlation is positive (Dematawewa and Berger, 1998), this apparent decrease in mortality with increase in milk yield could be due to the preferential treatment by the dairy producer towards the high producing cows compared to the low producing cows (Dematawewa and Berger, 1998) and it could also be explained that the physiological stress of high milk yield is not necessarily harmful to the welfare of a dairy cow as it relates to mortality risk.

On the other hand, lower milk yield at 1st test day was associated with increased hazards of on-farm mortality. Within herd the mortality hazards were 51% higher (HR: 1.52; CI: 1.50 – 1.54) among cows with lower milk yield [< (mean-1SD)] than cows with average milk yield (mean±1SD). Most probably such cows started their lactation with some disorders related to transition period and could not survive in that lactation.

Somatic cell score

Mortality increased with increase in somatic cell score. Cows with SCS ≥ 6.9, 5-6.9, 4-5 and 3-3.9 had 27%, 17%, 15%, and 10% higher hazards of mortality than cows with somatic cell score ≤ 3.0, respectively (Table 2). The increase in SCS has been reported to be associated with cases of clinical mastitis (de Haas et al., 2004) and clinical mastitis has been associated with increased risk of mortality in dairy cows (Bar et al., 2008; Hertl et al., 2011). These results are in agreement with the study of Thomsen et al.

(2006) who reported a 16 % increase in herd mortality for every 100,000 cell/ml increase in somatic cell count.

Body weight at calving

Body weight at calving was significantly associated with on-farm mortality. Within parity, cows with higher BW at calving [> (mean+1SD)] had 15% less hazards of mortality (HR: 0.85; CI 0.84 – 0.87) than cows within normal range of BW (mean±1SD). However, cows with lower BW at calving [> (mean-1SD)] had 13% greater hazards of mortality than the cows within normal range of BW (mean±1SD) as shown in table 2. The results of present study are in agreement with Frigo et al. (2010) who reported that greater BW and less BW change were favorably correlated with ketosis, metabolic diseases, infectious diseases, and other diseases. According to their findings the moderate to strong correlation between BW and diseases suggested that cows genetically inclined to have a greater BW in the early lactation would be less inclined to have diseases, particularly ketosis, metabolic diseases, and infectious diseases . As body condition score (BCS) and daily BW in early lactation are highly correlated (Toshniwal et al.,2008), a favorable genetic correlation between higher BCS and diseases (Lassen et al., 2003; Dechow et al., 2004) suggested that heavier cows are more inclined to have higher BCS and therefore less disease. Cows genetically inclined to have higher BCS lose less body condition in early lactation (Dechow et al.,2002) thereby likely to have less severe negative energy balance in early lactation, resulting in less metabolic disease (Dechow et al., 2004). Brotherstone et al. (2007) also reported that cows that were heavier at calving suffered fewer reproductive problems during the first lactation. Conversely, Hansen et al.

(1999) concluded that larger frame size Holstein cows had shorter productive lives and more health problems especially feet and legs and may not be economically justifiable. Frigo et al. (2010) explained that in Hansen's study the sire selection was determined by body dimension (stature, body depth, strength) and although cows in the large cow line weighed more, they may not have had higher BCS. Additionally, cows with large frames have more total body fat than smaller framed cows with equal BCS (Banos et al., 2006); therefore, a large-framed cow with an equivalent change in BCS as a small-framed cow will be mobilizing more adipose tissue and will likely be at greater risk for the development of metabolic diseases. In the current study the accuracy of BW measurements is questionable. Therefore these results are subjected to bias and should be used with caution.

Previous lactation dry period

Previous dry period (PDP) was significantly associated with mortality. The hazards of mortality were 6% less (HR: 0.94; CI: 0.91 to 0.96) in cows with short PDP (≤ 30 days) than the cows with average PDP (31 to 70 days). However, cows with longer PDP (> 70 days) had 8% higher mortality hazards than cows with reference dry period (31 to 70 days) as shown in Table 2. Shorter dry period has been shown to result in lower occurrence of subclinical mastitis or intramammary infection (Natzke et al., 1975; Pinedo et al., 2011), and mastitis has been associated with increased mortality in dairy cows (Bar et al., 2008, Hertl et al., 2011). This may suggest that cows with shorter dry periods were at lower risk of mortality due to lower intramammary infection compared to cows with relatively longer dry periods. Additionally, some studies indicated that short dry period strategy resulted in improved energy balance (Rastani et al., 2005; Watters et al. (2008). Rastani et al. (2005) reported that shortening the dry period from 56 to 28 days improved the energy balance and decreased the fat mobilization during first month of lactation. Similarly, lower NEFA concentrations for cows with shorter dry period (34 vs. 55 days) were reported by Watters et al. (2008). In addition, Santschi et al. (2011) indicated that short dry period (35 days) decreased the incidence of mild ketosis. Watters et al. (2008) also stated that culling was lower in the case of short dry period during the entire lactation. Improved energy balance and low incidence of diseases (mastitis and ketosis) might explain the reduced mortality among cows with short dry period. Cows with longer dry period (>70 days) had 9 % higher hazards of mortality (HR: 1.09; CI: 1.08 to 1.10) than the cows with reference dry period (30 to 70 days). Increased mortality in cows with longer dry periods could be the result of increased intramammary infection, as increased dry period length has been associated with increased intramammary infection (Enevoldsen and Sorensen, 1992; Dingwell et al., 2002; Robert et al., 2008; Pinedo et al., 2011). Also, the problems related to over conditioning around calving, might contribute to increase the hazards of mortality, as cows with longer dry period are more likely to accumulate greater body fat than the cows with average dry period.

Calving difficulty score

The increase in calving difficulty score was associated with increasing hazards of on-farm mortality. The mortality hazards were 8% (HR: 1.08; CI: 1.05 – 1.10), 9% (HR: 1.09; CI: 1.04 – 1.13) and 11% (HR: 1.11; CI: 1.05 – 1.17) higher for cows with calving difficulty score 3, 4 and 5, respectively compared cows with calving difficulty score 1.

Few studies reported the effect of calving difficulty score on cow survivability. Dematawewa and Berger (1997) reported that cows with calving difficulty score 5 (extreme calving difficulty) had 4% higher mortality than cows with score 1 (calving without assistance). Similarly, Bicalho et al. (2007) observed the effect of dystocia on cow survivability in the herd and found that cows with calving difficulty score 3 and 4 had 20 % higher hazards of death/culling than cows with calving difficulty score 1 and 2.

Twinning

Twin births were significantly associated with increased mortality in dairy cows. The mortality hazards were 7% higher (HR: 1.07; CI: 1.04 to 1.09) among the twin-calved cows than the single-calved cows. Similar to findings of present study, Bicalho et al. (2007) observed the effect of twinning on dam's survival and found that cow calved with twins had 42% higher hazards of death/culling than the cows calved single. Similarly, Thomson et al (2007a) reported that twinning increased the risk of becoming a loser cow. The "loser cows" are the cows that have generally compromised production and health and it has been reported that loser cows have a significantly higher risk of dying than the non-loser cows (Thomsen et al., 2007b). The increased risk of mortality among the cows carrying twins might be the result of problems associated with the twin births, such as retained placenta (Nielen, 1989) increased incidence of dystocia, metritis (Bell and Roberts, 2007; Hossein-Zadeh, 2010; Hossein-Zadeh and Ardalan, 2011; Mee et al., 2011), displaced abomasum, and ketosis (Fricke, 2001).

Calf gender

Cows carrying male were significantly at higher risk of mortality. The mortality hazards were 2% higher (HR: 1.02; CI: 1.01 to 1.03) for cows with male calves than cows with female calves. Male calves have been reported to be a risk factor for different reproductive disorders such as stillbirth (Meyer et al., 2000; Heins et al., 2006; Bicalho et al., 2007; Lombard et al. 2007; Potter et al., 2010) and dystocia (Heins et al., 2006; Hossein-Zadeh, 2010; Atashi et al., 2012) and these disorders have been associated with increased risk of mortality among dairy cows (Dematawewa and Berger, 1997; Bicalho et al., 2007).

Calving with stillbirth

The cows starting their lactation with stillbirth were at higher risk of mortality. The hazards of mortality were 10% higher among cows that started their lactation with the event of stillbirth compared to cows that gave birth to a live calf. Our finding was in agreement by the results of Bicalho et al. (2007). They reported that the cows that had stillbirth were at 41% increased hazard to death or to be culled from the herd than the cows that had love calves the cows experiencing stillbirths were at increased risk for different postpartum disorders such as prolapsed uterus, retained placenta, metritis, and displaced abomasum (Stevenson and Call, 1988; Correa et al., 1993). The higher incidence of these postpartum disorders may be associated with decrease survival of cows that had stillbirths (Bicalho et al., 2007).

Parity

Mortality hazards in dairy cows increased with increase in parity. The increase in hazards of on-farm mortality among cows of parity 2, 3, 4 and 5 was 54%, 111%, 150% and 180% compared with cows of parity 1, respectively (Table 2). The higher mortality with increasing parity has been reported previously (Faye and Perochon, 1995; Thomsen et al., 2004; Miller et al., 2008; Pinedo et al., 2010; Raboisson et al., 2011). The higher incidence of certain diseases related to increasing parity might be the reason of increased mortality among older cows (Thomsen et al., 2004).

Breed

The on-farm mortality rates significantly varied between the breeds. Holstein had significantly higher mortality hazards compared to Jersey, Ayrshire, Brown Swiss and Crossbreds. Only Guernsey had higher mortality than Holstein but that was not statistically significant. Crossbreds, Jersey, Ayrshire, and Brown Swiss had 25%, 21%, 15%, and14% less mortality hazards than Holstein, respectively (Table 2). Raboisson et al. (2011) also observed higher mortality in Holstein compared to Montbeliarde and Normande in France. Similarly, Thomsen et al. (2006) reported a higher mortality in Danish Holstein compared to Danish Jersey, Danish Red dairy, or other breeds (Danish red Holstein, Ayrshire and crossbreeds). Crossbred cows have been reported to have better survivability than purebred Holstein cows (Heins et al., 2006).

II) Herd Level Risk Factors

Milk yield

Higher herd level milk yield (HMY) was associated with decreased mortality. The mortality hazards were 23%, 12%, and 4% lower among cows in herds with high HMY (≥ 11,364 kg), medium high HMY (≥ 9,546 to < 11,364 kg), and medium low HMY (7,727-9,545 kg), respectively compared to cows in herds with low HMY (< 7,727 kg) as shown in Table 2. Decreased mortality with increased herd-level milk yield has been reported in previous studies. Alvason et al. (2012) described a 12%, 10% and 3% decrease in mortality rate in herds with milk yield ≥ 9,981 kg, 9,291kg to 9,980 kg, and 8,525 kg to 9,290 kg, respectively compared to herds with milk yield < 8,525 kg. Similarly, Thomsen et al. (2006) documented a 7% decrease (odds ratio: 0.93) in mortality for every 1,000 kg increase of mean milk yield per cow-year. Smith et al. (2000) observed a decrease in mortality from 7.7% to 7.1% and 5.9% for low (< 7,258 kg), medium (7,258 to 9,072 kg) and high (> 9,072 kg) producing herds, respectively. Batra et al. (1971) found a negative association between herd milk production and the percentage of cows that died in Canadian herds with constant herd size and increasing herd size. However, this association was statistically significant only for herds with increasing herd size. Similarly, Bascom and Young (1998) found numerically lower number of cows leaving the herd as died in herds with high milk production (11,400 kg) compared to herds with lower milk production (10,500 kg), although this difference was not statistically significant. It has been reported that progressive practices related to herd management are associated with increased milk yields (Pecsok et al., 1991; Sargeant et al., 1997). Therefore, lower mortality in high producing herds could be the cumulative effect of good management practices (Thomsen et al., 2006; Alvason et al., 2012).

Herd Size

The cow in larger herds had higher risk of mortality. The hazards of mortality for cows in larger herds (≥ 500 cow-years) were 92% higher, in high medium herds (200-499 cow-years) 48% higher, and in low medium herds (100-199 cow-years) 18% higher than cows in small herds (<100 cow-years; Table 2). In agreement to current study, Alvasen et al. (2012) described lower mortality rate (6.0%) for smaller herds (herd size, 50-99.9 cow-years) and highest mortality rate (7.5%) for larger herds (≥ 200 cow-years). Likewise, Raboisson et al. (2011) reported a +2% change in cow mortality for every 10 cow-years increase in herd size. Also, Pinedo et al. (2010) documented mortality rate of 5.8% for herds of 100 to 200 cows and 9.6% for herds > 3,000 cows. Similar association between mortality and herd size has also been documented in other studies (Smith et al., 2000; Hadley et al., 2006; Thomsen et al., 2006; McConnel et al., 2008; Dechow and Goodling, 2008). However, in an old Canadian study, no significant association between mortality percentage and herd size was observed (Batra et al., 1971). Larger herd size has been correlated to less attention to individual cows (Dohoo et al., 1984; Nørgaard et al., 1999). Along with other dynamics, the less time spent on individual cows in larger herds could be one of the factors for increased mortality, as in such scenario, the problem cows might not be identified in time for treatment or culling thereby increasing the on-farm mortality. One study indicated that fewer cows per employee decreased the risk of involuntary culling in profitable cows (Weigel et al., 2003). This implies that improving the individual attention per cow through proper labor management or the use of precision dairy farming technologies for animal monitoring could be helpful to reduce the high levels of mortality in larger herds.

Herd calving interval

As the herd calving interval (HCI) increased, mortality among cows increased. Cows in herds with longer HCL (> 16 months) had 21% higher hazards of mortality, and with average HCI (15-16 months) had 16% higher mortality hazards compared with cows in herds with reference HCI (12-14 months; Table 2). In agreement to present study, Alvasen et al. (2012) observed that the risk of mortality was 22 % higher in herds with calving interval ≥ 422.0 days compared with the herds with calving interval 389.3 days. Likewise, Raboisson et al. (2011) reported a +1% change in cow mortality for every 10 days increase in calving interval. Similarly, McConnel et al. (2008) found that the herds with average calving interval of >13.9 months had 78 % higher odds of mortality than the herds with an average calving interval of <13 months. Herd level calving interval is an indirect reflection of good management (Alvasen et al., 2012). High levels of quality management are needed to get a low average calving interval (Raboisson et al., 2011; Alvasen et al., 2012) which might have beneficial effects on lowering cattle mortality in herds with short calving interval.

Herd somatic cell score

The hazards of mortality among cows increased with the increase in herd somatic cell score (HSCS). The hazards of mortality were 13%, 22%, 30%, and 36% higher for herds with low medium HSCS (2.1 to 2.5), medium HSCS (2.6 to 3.0), medium high HSCS (3.1 to 3.5), and high HSCS (≥ 3.6) respectively compared with herds of low HSCS (≤ 2.0). In agreement to this study, Thomsen et al. (2006) reported a 16% increase in the risk of mortality for every 100,000 cell/ml increase in herd's average somatic cell count. Good management (clean and accurate vs. quick and dirty) has been associated with reduced bulk milk somatic cell count (Barkema et al., 1999) and could explain the lower mortality in such herds with lower somatic cell score.

Herd stillbirth percent

Cows in herds with higher herd stillbirth percent (HSP) had significantly higher mortality. The hazards of mortality were 40%, and 26% higher among cows in herds with high HSP (> 25%), and medium HSP (16 to 25%) compared to cows in herds with low HSP (≤ 5%). In accordance to our findings, Thomsen et al. (2007a) studied the risk factors for loser cows (cows more prone to morbidity and mortality) and found that every 5% increase in the proportion of stillborn calves was associated with 40% increase in loser cows. They used the herd-level stillbirth as an indicative of management. Better management (frequency of observation of cows during late gestation or the use of video camera) was associated with decreased herd-level stillbirth rate (Vernooy et al., 2007). Therefore the lower mortality among cows in herds with lower stillbirths might be the result of good management.

The findings of herd level risk factors strongly support the concept of quality management to reduce dairy cow mortality. Maintaining high production without compromising cow welfare is possible with enhanced management practices and improved cow friendly housing (Nigel, 2012).

Conclusions

This study identified different cow and herd level risk factors for mortality in DHIA Midwest dairy cows. Increased mortality in cows was associated with 1st test day higher fat to protein ratio, higher fat %, lower milk protein %, higher SCS, higher MUN, longer calving interval, multiple calves, male calves, increased calving difficulty score, and increasing parity. Mortality was lower in cows with higher 1st test day milk and higher milk protein %. The hazards of mortality were higher among cows in herds with larger herd size, higher somatic cell score, increased percentage of stillbirths, and increased calving interval. Mortality risk was lower among cows in herds with high milk production. The first test day production records could be helpful to identify the cows at higher risk of mortality. The cumulative effects of cow and herd level risk factors indicate that quality management in transition period would be useful to reduce the mortality in dairy cows.

Table 1: Explanatory variables for risk factor analysis of mortality among Midwest DHIA dairy cows.

Main area*	Explanatory variables
Herd Characteristics	Herd size
	Herd-level milk yield
Production	1st test day milk yield
	305ME milk yield
	Somatic cell score
Reproduction	Previous calving interval
	Herd-level calving interval
	Herd-level stillbirth
	Calving ease
	Stillbirth
	Twinning
	Calf sex
Transition cow management	Fat to protein ratio
	Milk fat %
	Milk protein %
	Milk Urea Nitrogen
	Previous lactation dry period
	1st test day milk yield
	Calving started with stillbirth
	Body weight at calving
Genetics	Breed
	Milk yield
	Twinning
	Calving ease
Milking management	1st test day somatic cell score
	Herd-level somatic cell score
Cow attributes	Breed
	Parity

*Grouping of explanatory variables into different management areas has been derived from Thomsen et al. (2007).

Table 2: Risk factors for mortality among Midwest DHIA dairy cows calved during Jan. 2006 to Dec. 2010

Variable	Categories	Hazard Ratio[1]	95% CI[2]
Cow level risk factors			
1st test day milk yield			
	Medium*	1.0	Ref[3]
	High	0.95	0.934 – 0.961
	Low	1.51	1.491 – 1.531
Milk fat %			
	Medium*	1.0	Ref
	High	1.43	1.415 – 1.451
	Low	1.14	1.121 – 1.155
Milk protein %			
	Medium*	1.0	Ref
	High	0.95	0.940 – 0.967
	Low	1.38	1.361 – 1. 398
Fat to protein ratio			
	1.0 to 1.6	1.0	Ref
	< 1.0	0.99	0.968 – 1.008
	> 1.6	1.43	1.413 – 1.446
Parity			
	1	1.0	Ref
	2	1.54	1.524 – 1.565
	3	2.11	2.084 – 2.143
	4	2.50	2.463 – 2.543
	≥5	2.80	2.752 – 2.851
Milk Urea Nitrogen (MUN)[m2]	Medium†	1.0	Ref
	High	1.14	1.103 – 1.181
	Low	1.16	1.130 – 1.196
Somatic cell score			
	≤ 3.0	1.0	Ref
	3.1 – 4.9	1.10	1.086 – 1.112
	5.0 – 5.9	1.15	1.129 – 1.173
	6.0 – 6.9	1.17	1.146 – 1.198
	≥ 7.0	1.27	1.240 – 1.292

Table 3:(Continued) Risk factors for mortality among Midwest DHIA dairy cows calved during Jan. 2006 to Dec. 2010

Variable	Categories	Hazard Ratio[1]	95% CI[2]
Body weight at calving	Medium*	1.0	Ref
	Low	0.85	0.836 – 0.868
	Medium	1.14	1.121 – 1.149
Calving interval[m3]		1.03	1.032 – 1.036
Dry period[m3] (days)			
	31 – 70	1.0	Ref
	< 30	0.94	0.911 – 0.963
	> 70	1.08	1.064 – 1.095
Breed			
	Holstein	1.0	Ref
	Crossbred	0.75	0.726 – 0.774
	Brown Swiss	0.86	0.816 – 0.900
	Ayrshire	0.85	0.774 – 0.939
	Jersey	0.79	0.767 – 0.813
	Guernsey	1.06	0.968 – 1.154
	Others	0.69	0.634 – 0.750
Calving difficulty score	1	1.00	Ref
	2	1.03	1.009 – 1.050
	3	1.08	1.053 – 1.104
	4	1.09	1.042 – 1.134
	5	1.11	1.047 – 1.170
Calving with stillbirth	No	1.0	Ref
	Yes	1.10	1.076 – 1.123
Twinning			
	No	1.0	Ref
	Yes	1.07	1.045 – 1.092
Calf gender			
	Female	1.0	Ref
	Male	1.02	1.012 – 1.032

Table 4:(Continued) Risk factors for mortality among Midwest DHIA dairy cows calved during Jan. 2006 to Dec. 2010

Variable	Categories	Hazard Ratio[1]	95% CI[2]
Herd level risk factors			
Herd size			
(cow-years[4])	20-99	1.0	Ref
	100-199	1.18	1.161 – 1.197
	200-499	1.48	1.453 – 1.498
	≥ 500	1.92	1.889 – 1.947
Herd 305ME[5] milk			
yield (kg)	Low‡	1.0	Ref
	Medium low	0.96	0.932 – 0.986
	Medium high	0.88	0.853 – 0.901
	High	0.77	0.747 – 0.791
Herd calving interval			
(months)	12-13	1.0	Ref
	14-16	1.16	1.144 – 1.170
	>16	1.21	1.21– 1. 259
Herd somatic cell			
score	≤ 2	1.0	Ref
	2.1 to 2.5	1.13	1.111 – 1.150
	2.6 to 3.0	1.22	1.204 – 1.245
	3.1 to 3.5	1.30	1.273 – 1.322
	≥ 3.6.	1.36	1.332 – 1.390
Herd stillbirth %			
	≤ 5	1.0	Ref
	6 to 15	1.10	1.081 – 1.103
	16 to 25	1.26	1.236 – 1.283
	> 25	1.40	1.339 – 1.453

[1]Hazarda ratio = hazards of having greater mortality rates. [2]95% confidence interval: If 95% CI does not include 1, it indicates statistically significant difference at $P < 0.05$.
[3]Reference category. [4]A cow that remains in the herd for one year equals to one cow-year. [5]305ME = 305-d mature equivalent.
[m2]The estimated hazards ratios and CI are from model-2.
[m3]The estimated hazards ratios and CI are from model-3.
*Medium = (mean ± 1 SD), high > (mean + 1 SD), low < (mean - 1 SD).
†MUN medium = (mean ± 6), low < (mean - 6), high > (mean + 6).
‡low (< 7,727 kg), medium low (≥ 7,727 to 9,545 kg), medium high (≥ 9,546 to 11,363 kg), high (≥ 11,364 kg).

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