GENETICS OF HEAT TOLERANCE FOR DAYS OPEN IN US HOLSTEINS

by

SAIDU OSENI

(under the Direction of Ignacy Misztal)

ABSTRACT

The objectives of the first study were to present statistics on the seasonality of calving and regional trends for days open (DO) across the US. Data included 8,676,915 records on DO for Holsteins from 1997 to 2002 covering all regions of the U.S. Fixed effects in the model included herd, parity, milk-class, state × month of calving (MOC), year of calving × MOC and parity × MOC. Least squares means of DO were highest for calvings in March and lowest for calvings in September. Distributions of DO were bimodal for some months of calving; the second mode at > 200 d was highest in the Southeast but also could be observed in TX, WI and CA. High level of heat stress for DO exists in the Southeast and in selected states of the Midwest and the Southwest.

A second study investigated the effect of different editing of DO records on the genetic parameters of DO and pregnancy rates (PR). Data included first parity 305-d milk yield and DO records in eight states of the US. Days open upper limits were set to 150, 200, 250, 300 and 365 d. A bivariate animal model for DO (or PR) and 305-d milk yield included fixed effects of herd-year, month of calving and age of cow, and random animal and residual effects. Genetic and residual variances for DO changed up to 8 times as DO upper bound increased from 150 d to 365 d. Estimates of heritability for DO varied between 3 and 6 %. For most states, estimates of heritability for 150 and 200 d bounds were similar, and lower than estimates for bounds $\geq$250 d. Heritabilities for PR varied by the length of the VWP. Records of DO > 250 d carry little genetic information whereas records < 120 d carry more or less information depending on management.

In a third study, a reaction norm approach was used to estimate the genetic parameters of DO with a model that accounted for heat stress. The reaction norm model included the effect of animal with random regression on a heat stress index (HI). Results indicated that all the estimated parameters varied by month of calving. The results of a four-trait model based on calving seasons validated the reaction norm model.

INDEX WORDS: Days open, Pregnancy rate, Heat stress index, Month of calving, Reaction norm, Genetic parameters, Regions, US

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SAIDU OYAREKHUA OSENI

B. Agric. (Hons) Obafemi Awolowo University, Ile-Ife, Nigeria, 1992

M. Phil. Obafemi Awolowo University, Ile-Ife, Nigeria, 1997

A Dissertation Submitted to the Graduate Faculty of The University of Georgia in Partial
Fulfillment of the Requirements for the Degree

DOCTOR OF PHILOSOPHY

ATHENS, GEORGIA

2004

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SAIDU OYAREKHUA OSENI

Major Professor:	Ignacy Misztal
Committee:	Keith Bertrand Romdhane Rekaya Joe West William Graves

Electronic Version Approved:

Maureen Grasso
Dean of the Graduate School
The University of Georgia
May 2004

ACKNOWLEDGEMENTS

I want to express my deep sense of gratitude to Dr. Ignacy Misztal for the opportunity and privilege to work under his supervision and guidance. His advice, patience, dynamism, humor and financial support are truly appreciated. I would also like to thank Dr Keith Bertrand for his encouragement and friendship during the course of my program. My thanks go to Dr Romdhane Rekaya for his assistance, friendship, interest and encouragement. The efforts of other members of my committee are appreciated too. Drs Graves and West gave timely clarifications on many issues on reproduction, extension and heat stress–related topics.

I want to thank past and current members of the Animal Breeding and Genetics Group who made my experience at UGA a memorable one. Specifically, I want to thank Robyn Sapp (and family), Drs Kath Donoghue, Paulo Nobre, Hiro Iwaisaki and Jesus Arango, Jarmila, Travis, Kelly, Matt, and Chung-Huoy. The friendship and efforts of Dr. Shogo Tsuruta are appreciated. Thanks also to Mike Kelley, Dr. Andra Nelson, Dell Little and Linda Heusner for their support and friendship. My utmost gratitude to the following people for extreme kindness and compassion: Mrs. Anna Misztal, Drs Akinloye Ojo, Nicholas Oppong and Patricia Wilson. I also wish to express gratitude to the staff and nurses of the Athens Nurses Home, Athens, GA, for providing free medical services to members of my family.

I want to say “thank you” to my wife, Zinetu, the love and priceless jewel of my life, and to my children – Taslim, Tawakalit and Abdul-Salaam for the sacrifices they made. Special thanks to my father, Prof. Z. I. Oseni and to my brothers – Fab, Lawal, and to AKO for their prayers and support. I am also grateful to the authorities of the Obafemi Awolowo University, Ile-Ife, Nigeria for granting me the study leave to do this program. Finally, I want to acknowledge the support, inspiration and encouragement of Prof. E.B. Sonaiya who has made a huge difference in my life, and to Prof. A.O. Aderibigbe, Drs. S.M. Odeyinka, and A. Akinfala, and Messrs K.M. Ajuwon and S.I. Ola, and to Mrs. I. Adeogun and other academic staff of the Department of Animal Science, OAU, Ile-Ife, Nigeria for their support and prayers.

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CHAPTER 1

INTRODUCTION

Globally, there is a heightened concern about the declining trends in fertility and reproductive performance in dairy herds. Reasons for this trend have been attributed, partly to the effect of Holsteinization or use of North American germ plasm, and partly to the intense and prolonged selection for production traits, with the exclusion of functional traits like fertility, fitness and health-related traits. Fertility traits have a high environmental component, which implies that genetic improvement through selection will be a slow process. Also, there is no consensus among authors regarding what trait adequately defines a multi-dimensional character like fertility. Evidence of this is the inclusion of different fertility measures in national indexes by various countries. While the United States recently included daughter pregnancy rate as the measure of fertility in Net Merit Index, the United Kingdom uses calving interval, while most Scandinavian countries use various definitions and combinations of non-return rate to some specified days in milk, and interval traits in their Total Merit Indexes. Further, differences exist with respect to the definitions of male and female fertility, heifer and cow fertility, and whether fertility is the same trait across all parities. These problems are further compounded by the effect of management decisions on fertility traits through lengthened VWP, use of BST and preferential treatment of cows. Reports have indicated that the deterioration in fertility levels is further exacerbated by high thermal stress suffered during the hot seasons of the year.

The above scenario shows some of the complexities involved in the study of fertility traits. Currently, major dairying countries include some fertility measures in their national genetic evaluations for production and fertility. While this is remarkable, the issue of genotype by season interaction effect for fertility traits has not been adequately investigated. Seasonal thermal stress causes huge economic losses to the dairy industry through depressed reproduction, delayed re-breeding and prolonged days open and calving intervals. Most studies have focused on environmental modifications as a way to redress the situation. Genetic studies on the effects of heat stress in dairy cattle reproduction showed significant differences between animals in rectal temperature, respiration rates and body temperature, suggesting the possibility of selecting animals for heat tolerance. However, questions remain on how to quantify the level of heat stress in different regions as well as the modeling of the genetic component of heat tolerance especially in hot climates. In such regions, the advantages of including heat tolerance merit in regional genetic evaluations for dairy cattle are obvious. Most sires are tested and proven in cold or mild climatic regions of the world. But proven sires are used extensively through out the world, including hot climates. Further, a recent report by McDaniel et al. (1999) showing low correlations between breeding values for fertility and production traits indicated that top sires for yield traits are not the best for fertility. Also, Lopez-Gatius (2003) reported that heat stress aggravated all measures of fertility and contributed significantly to the deterioration in reproductive performance when compared to the same measures in cold seasons.

These studies draw attention to the importance of evaluating animals for heat tolerance for fertility traits especially in hot climates. This, however, will require the development of some methodology for quantifying heat stress and sound genetic modeling to identify heat tolerant animals. The objective of this study was to examine some genetic aspects of heat tolerance for days open in US Holsteins.

CHAPER 2

REVIEW OF LITERATURE

1.0 Fertility traits

1.1 Trait definition

Fertility is a composite and complex trait. The problem of trait definition in genetic evaluations for fertility traits has been raised by several authors (Thaller, 1997; VanRaden and Tooker, 2003). Generally, fertility can be categorized into 2 classes as: (a) measures of success such as non return rate, conception rate and number of insemination to conception and (b) interval measures such as days open (DO), calving interval, days to first service, service period, etc. Success measures are usually categorical, discontinuous characters, available early and require sophisticated analyses whereas the interval traits are continuous with substantial skewedness (Hoeschele, 1991; VanRaden and Tooker, 2003). In addition, interval traits have higher heritability than the success measures but are highly influenced by management factors (Norman et al., 2002).

Fertility traits have also been defined as independent male (Estimated Relative Conception Rate) and female traits (daughter pregnancy rate (DPR) and age at first calving in heifers) (Weigel and VanRaden, 2003). According to these authors, DPR, which is derived from DO, is a female fertility trait, which measures a cow's ability to cycle, show estrous and conceive in a timely manner while the ERCR measures a bull's ability to produce fertile semen that will result in a pregnancy. All these steps represent attempts by authors to capture/identify a trait that is representative of all the varied components of fertility.

Interval traits are subject to the decision policies of dairy producers with regards to when to re-breed a cow, breeding efficiencies (through heat detection) and various other management and nutritional factors (Hayes et al., 1992). Also, most DHI records may not contain detailed information on heat detection efficiency, estrous synchronization, or the effect of hot weather on mating decisions – which are crucial information for a comprehensive evaluation for fertility. According to Misztal and Rekaya (2004), an interval trait like DO is a composite trait, with each component having a different distribution. These components are largely affected by management factors, including reproductive protocols (estrous synchronization and timed AI), use of lactation promotants such as BST, intentional delay in re-breeding, seasonal effects, etc. All the above factors were shown to affect the distribution of DO. These authors presented evidence showing that the distributions for this trait depended on BST use, herd production levels, season of calving and estrus synchronization status. They recommended that all these components be properly partitioned and evaluated separately.

1.2 Trends in fertility traits

Declining trends in fertility levels in the dairy industry have been widely reported (Silva, 1998; Washburn et al., 2002; Petersen et al., 2002; Rajala-Schultz and Frazer, 2003). These reports indicated longer time to first estrus, increasing days open, service period and number of services/inseminations per conception and decreasing pregnancy rates. Wall et al., (2003) reported an unfavorable decline in the breeding values of all fertility traits in recent years, with calving interval, days to first service and number of inseminations to conception increasing and NR56 decreasing (i.e. it is more likely that a cow will return to service).

These declining trends in reproductive efficiency in dairy cattle represent a global problem. Reports of declining trends in first service conception rates have been reported in Australia

(Macmillan, et al., 1996), in the UK (Royal et al., 2000), and in Ireland (Roche et al., 2000). As such, these declining trends in reproductive performance present a growing international concern about undesirable genetic changes in fertility, disease incidence and overall stress in spite of improved nutrition and general management (McGuirk, 2000). One reason largely given for these undesirable trends in fertility has been the genetic relationship between milk production and reproductive traits (Abdullah and McDaniel, 2000; Veerkamp et al., 2001). The general conclusion has been that selection based primarily on production traits increased the incidence of fertility-related problems leading to reduced reproductive performance.

1.3 Effect of management

Evaluation of cattle for fertility is further complicated by preferential husbandry by herdsmen, depending on one or several factors. According to Olori et al., (2003), there is an intricate relationship between milk production, fertility and cow survival. It is known that the probability of being culled is lower for cows with high milk yield (Ranberg, 1997). Also, Weller (1989) reported that among infertile or sub-fertile cows, a farmer is more likely to re-inseminate and less likely to cull those with superior milk production or daughters of elite sires (Gröhn, 1986). This was corroborated by Ducrocq et al., (1988) who indicated that milk yield was a significant factor in determining whether a Holstein cow was retained in the herd. Also, a cow that remained open for an extended period or a cow that is low-yielding is more likely to be culled. Reports by Farin et al., (1994), using days to first service, showed that NC dairy producers stopped breeding their low yielding cows sooner than their high yielding cows. As a result, the cows with prolonged DO are not random samples of all cows.

All the above issues regarding culling decisions can cause selection bias (Marti and Funk, 1994). These authors argued that in a herd where low-yielding cows are more likely to be culled, higher yielding cows tend to have longer DO (and CI) than do their herd mates. This biased association is super-imposed on other biological causes for the genetic associations between yield and fertility traits. On account of these high interference of management with fertility measures, several authors (Olori et al., 2003; Marti and Funk, 1994) proposed the inclusion of cow survival data in the genetic evaluations for fertility in order to have less biased parameter estimates since culled cows can still contribute some information to the analyses.

Effects of management also include lengthened VWP, which varies among herds and between cow groups within herds. The application of BST and/or the use of some reproductive management protocols (timed AI, estrus and ovulation synchronization) represent management factors that affect interval traits. In spite of the high influence of management on these traits, Norman et al., (2002) concluded that DO represents the best single measure of fertility traits examined for genetic evaluation for cow fertility.

1.4 Genetic parameters for fertility traits

Numerous reports in the literature indicate that heritability estimates for fertility measures are low ($\leq$5%). Some researchers have concluded that due to low heritability, selection for improved fertility would not be feasible. Others have concluded that in spite of the low heritability, AI sires should still be evaluated for reproductive performance in order to prevent further decline in fertility levels resulting from the correlated response due to selection for higher yields (Abdallah and McDaniel, 2000; Norman et al., 2003). This second approach was adopted by Scandinavian countries for several decades now. They evolved a system whereby sires are routinely evaluated for functional traits of health and fertility (Philipsson 1981; Philipsson and Lindhe, 2003). According to Berglund and Philipsson (2001), selection for total merit (including functional traits) has counteracted the expected negative response in fertility from selection for increased production only. Although progress towards greater milk production may be less, their models suggest improved economic efficiency when functional traits are included in selection programs (Philipsson et al., 1994).

Further evidence of high genetic variability for fertility traits was provided by McDaniel et al., (1999) who indicated that some Holstein males that have been extensively used as bull sires had very unfavorable breeding values for non return rate and for days to first service for their daughters. They recommended the incorporation of cow (daughter) reproduction into selection decisions. Similar conclusions were drawn by Weigel (2000) who presented evidence of differences in service bull and daughter fertility across independent datasets and reported that national genetic evaluations for female and male fertility are justified on account of the high economic value of these traits to dairy producers. Wall et al., (2003) also indicated that although heritability estimates for fertility traits are low, there was exploitable genetic variability in these traits as observed in variance component estimation and PTA variance, implying that top and bottom sires for fertility traits can be identified and selected.

More arguments have been presented in favor of the inclusion of the functional traits in selection indices. These include the facts that these traits have large economic values and high genetic coefficients of variations (Philipsson, 1981; Hermas et al., 1987; Raheja et al., 1989; Hodel et al., 1995; Oltenacu et al., 1991; Norman et al., 2002; VanRaden, 2003). Table 3.1 presents some genetic coefficients of variations for some production and functional traits pooled from literature sources. Thus, the inclusion of fertility traits is expected to prevent further deterioration in reproductive performance and to reduce the global effect of Holsteinization and increase US competitiveness in the international dairy market. In 2003, a new net merit index was released (VanRaden, 2003), in which DPR has 7% of the total index. According to this author, the new index is expected to result in faster progress in the improvement of functional traits but slightly less progress for yield traits. Wall et al., (2003) reported that the correlation of fertility evaluations in the UK with 8 other countries (including the US) showed that highest correlation (0.76) for US DPR with the UK CI, indicating the increasing global competitiveness of US sires with the incorporation of fertility into the Net Merit Index.

1.5 Genetic correlations

Many reports on the genetic associations between yield and fertility traits indicated moderate antagonistic relationships (Pryce et al., 1998; Dematawewa and Berger, 1998; Veerkamp et al., 2001; Abdullah and McDaniel, 2000; Veerkamp et al., 2001; Roxstrom et al., 2001). These reports largely reflected a range of genetic correlations of 0.2 to 0.4 and have generally concluded that many generations of selections for yield traits led to the deterioration in functional traits. They recommended the inclusion of daughter fertility in selection indexes to prevent further deteriorations in fertility levels.

Among male and female fertility traits, Hodel et al., (1995) reported that the correlations between these measures for Swiss Simmental were essentially zero, implying that the mechanism for their genetic determination are independent. The same may apply to heifer and cow fertility measures. Some authors (Ron et al., 1984; Weller and Ron, 1992) reported low genetic correlations for Israeli Holsteins for heifer and cow fertility.

1.0 Effect of heat stress on reproductive performance

2.1 Heat stress

The effect of heat stress on reproductive performance is worldwide and inflicts heavy economic losses on the dairy industry (Hansen, 1997; Berman and Wolfenson, 1992). In particular, summer heat stress is a major contributing factor to low fertility in lactating cows in hot environments (Wolfenson et al., 2000). Fertility traits are drastically affected by seasonal

Table 2.1. Heritabilities and genetic coefficient of variations (CV) for some functional and productive traits pooled from the literature.

Trait	**Heritability (%)**	**CV (%)**	**Authors**
Protein		7.0	Norman et al., 2002
PL		16.0	„
DPR		13.0	„
BCA-milk	18	6.3	Raheja et al., 1989
BCA-fat	20	6.8	„
% fat	58	6.7	„
NIC	3	9.9	„
DO	3	8.8	„
DFI	5	8.3	„
CR	2.3	10.9	Buxadera & Dempfle, 1997
NSC	3.2	11.2	„
CS	3.0	6.2	„
DPR		13.0	VanRaden, 2003
PL		16.0	„
Protein		7.0	„
NR90	1.1	6.5	Hodel et al., 1995
SP (cow)	3.8	30.2	„
Clinical mastitis		10 – 26	Philipsson & Lindhe (2003)
Stillbirth rate		3 – 16	„

PL = productive life; DPR = daughter pregnancy rate; BCA-milk = breed class average –milk; NIC = Number of inseminations to conception; DO = days open; DFI = days to first insemination; CR = conception rate; NSC = Number of services per conception; CS = calving success; SP(cow) = service period (cow); NIS = number of inseminations to conception.

heat stress. Cavestany et al., (1985) showed a drop in CR from about 40 – 60% in cooler months to 10 – 20 % or lower in the summer months, depending on the severity of thermal stress. Depression in fertility levels during the summer has been attributed primarily to heat stress since the experimental applications of heat stress to cows reduced pregnancy rates and increased incidences of embryonic mortality (Putney et al., 1988; Ealy and Drost, 1993).

According to Al-khatanani et al., (1999), heat stress may act at several physiological time points to disrupt the establishment of pregnancy, including before ovulation, on the day of insemination, and after embryonic development has proceeded. These authors noted that the depression in pregnancy rate in the summer is likely to be even stronger than indicated by 90 –d non-return rate because of increased frequencies of unobserved estrus as reported by Thatcher and Collier (1986). Thatcher et al. (1978) reported a postponement of first normal estrous during warm season as well as a reluctance to conceive once inseminated.

The delayed effect of heat stress results in low fertility in the autumn (October and November), although ambient temperature are lower and cows are no longer subjected to heat stress (Berman and Wolfenson, 1992). Badinga et al. (1985) reported that CR in FL for Holstein cows were about 35 – 40 % in the autumn, compared to > 50 % in the winter period. Heat stress also affects the intensity (Nebel et al. 1997) and duration (Rutledge, 2001) of estrus behavior. Nebel et al., (1997) showed that Holstein cows in estrus during the summer have 4.5 mounts per estrus vs. 8.6 mounts during the winter. Abnormal estrous behavior was also attributed to lethargy, which masks the intensity of estrous display and results in poor estrous detection. According to Hansen and Arechiga (1999), the establishment and maintenance of pregnancy is difficult in lactating dairy cows exposed to heat stress because of reduction in estrous detections rates, reduced pregnancy rates and proportion of cows that maintain pregnancy. The consequences of heat stress, according to Silva et al., (1992) are exhibited through increases in days to first service, service period, days open and calving intervals by 7, 7, 12 and 13 days respectively.

2.2 Seasonal trends for heat stress

Marked differences between seasons in fertility traits have been reported for days open (VanRaden et al., 2003); non return rate (Mantysaari and Van Vleck, 1989); conception rate (Hillers et al., 1984; Faust et al., 1988; Eicker et al., 1996); first service conception rates (Buxedera and Dempfle, 1997) and number of services per conception (Faust et al., 1988). The above effects of heat stress have been attributed to high temperatures above the thermo-neutral (comfort) zone of the cow (Gwaszdauskas, 1981; Hansen, 1997). Differences between seasons in estrous detection rates have been reported by Thatcher and Collier (1986). These authors showed that the percentage of undetected estrous was about 75% during the summer and 50% during the rest of the year in a Florida dairy. In Israel, Ron et al., (1984) reported that CR in the summer were about 20% compared to about 50% in the winter while Ingraham et al., (1974) cited records as low as 10% in Mexico and southern US in the summer months. This low summer fertility syndrome (Berman and Wolfenson, 1992) has been described as a multi-factorial problem. These authors noted that the exposure of dairy cows to heat stress from a few days before estrus, through estrus, insemination, ovulation and the first 2 – 3 weeks of pregnancy may affect embryo development and endanger its survival. They noted that any interference with any stage of the sequence of events could adversely affect the normal progress of pregnancy.

Lopez-Gatius (2003) examined some (re)productive parameters for dairy cattle in warm and cold seasons over a 10-year period in Spain and presented startling evidence of the effects of heat stress on female reproduction. According to this author, overall cyclicity and PRs of all AI cows and cows in the warm period significantly decreased over the 10-year period, in sharp contrast to results in the cool periods, which remained relatively constant. This author reported similar trends for the incidence of inactive ovaries and ovarian cysts, both of which increased with time for all cows and, specifically, cows examined during the warm periods. Further, according to this author, regression analyses showed that a 1000 kg increase in average milk yield was related to decreases of 3.2 and 6% in PR, 4.4 and 7.6% in incidences of cyclicity and an increase of 4.6 and 8% of cases of inactive ovaries for all AI cows and for cows examined during the warm periods. This author further noted that high cases of inactive ovaries in the warm periods have profound negative impact on the commercial dairy since DO and CI are prolonged. Previous reports (Abdallah and McDaniel, 2000; Washburn et al., 2002) have implicated the rising average milk yield as the causal factor for the depressed reproductive performance. However, according to Lopez-Gatius (2003), when data is stratified by season, then the effects of high milk yield is further exacerbated by heat stress in the warm periods whereas these reproductive parameters remained largely unchanged in the cool season. The author summarized that cool seasons appear to preserve fertility and reduce the risk of reproductive disorders, irrespective of the level of milk yield. A previous report by Berman et al., (1985) noted that there were reductions in the thermoregulatory abilities of cows in the face of heat stress as a result of selection for milk production and that this magnifies the seasonal depression in fertility caused by heat stress.

2.3 Genetic parameters for reproductive traits in different seasons

Questions have been raised about changes in genetic parameters for reproductive traits in different seasons. Studies by several workers (Hahn, 1969; Seykora and McDaniel, 1983; Faust, et al.,1989) using paternal half-sib methods, have indicated that estimates of heritability for days open and first service conception rate were higher for spring than for fall calvings, indicating a significant sire by season interaction effect. Further, Seykora and McDaniel (1983) showed that the genetic association between milk yield and days open was more antagonistic for calvings in spring when compared to other calving seasons. These authors concluded that genetic differences in fertility levels and genetic correlations between milk yield and fertility traits are best observed under sub-optimal conditions.

2.4 Selection for heat tolerance

According to Berman et al., (1985), selection for heat tolerance is made difficult by the antagonistic relationship between milk yield and body temperature regulation and by the fact that dairy cattle are not typically tested for genotype by environment interaction. This indicates that emphasis on relief has been largely on environmental modifications. However, several investigators have reported substantial genetic variations for heat tolerance for production (Nardone and Valentini, 2000; Ravagnolo and Misztal, 2000) and reproductive traits (Ravagnolo and Misztal, 2002).

Current trends in the dairy industry indicate that the best bulls are currently proven primarily in states/regions with moderate climate such as NY, WI, PA and CA and in countries like The Netherlands, France, Germany, etc (Misztal, 1999). Some hypotheses proposed by this author are: (a) selection for milk production decreases heat tolerance and (b) current top sires may not be the best for hot climates with respect to (re) productive traits. This author argued that the calculation of sire proofs for heat tolerance for (re)productive traits would allow for sire selection specifically for hot climates. The fact that these sires may not be the top sires for production traits imply that their semen will be less expensive. If this hypothesis were true, then the current use of top sires would have negative economic consequences in hot climates since their daughters may not be the best cows for hot climates. The first hypothesis was proved by Ranagnolo and Misztal (2000) who reported that genetic selection for milk production reduced heat tolerance (r_g = -0.36) but that joint selection for both traits was possible.

The modeling of the genetic component of heat stress for non-return rate (NR) in Southeastern US was conducted by Ravagnolo and Misztal (2002). These authors estimated genetic parameters for NR using a model with a random regression on temperature-humidity index (THI). They reported that the variance of heat stress was zero at THI =70 but it was as large as the general additive variance at THI = 84 for NR at 90 d, indicating that genetic variation in heat tolerance exists for NR90 d at high levels of THI among Holsteins.

2.0 Reaction norm

Studies by several researchers (Hahn, 1969; Seykora and McDaniel, 1983; Faust et al., 1989) have indicated seasonal differences in the genetic parameters for days open and first service conception rates (FSC). In a genetic context, these studies suggest some genotype by environment interaction for these traits. They also imply that DO and FSC in different calving seasons/months could be treated as different traits, since the physiology will be different and the performance in different seasons will be influenced to some extent, by different genes though partly by same genes. Consequently, measures of DO or FSC across calving seasons are genetically correlated and the magnitude of the correlation reflects the extent to which the same genes are involved (Falconer, 1990).

The difference between the measurements of a genotype or of a population in different environments is the environmental sensitivity or the reaction norm (Woltereck, 1909; Falconer, 1990; De Jong 1995; Falconer and Mackay, 1996). In order to quantify environmental sensitivity, each genotype is evaluated in each environment and values (means for individuals) are assigned to each environment (defined as calving season, plane of nutrition, or herd, etc). The sensitivity or reaction norm of a genotype is the regression of genotype performance on the environmental gradient (Falconer and Mackay, 1996; Kolmodin et al. 2002). The reaction norm approach is useful when phenotypes change gradually and continuously over an environmental gradient (De Jong, 1995) and has been applied in the evaluation of animals and plants for phenotypic plasticity or robustness across different environments (Stratton, 1998; Kolmodin et al., 2002). Thus, the reaction norm methodology may find possible applications in the modeling of genetic parameters of a fertility trait across environments defined as seasons of calving. Such a study would show differences between calving seasons in the estimated parameters as well as possible changes in these parameters across calving seasons.

3.0 Topics for research

The foregoing review of the literature raises the following research questions:

- What is the extent and distribution of heat stress for fertility traits in the US?
- Are there regional/state differences with respect to fertility in the US?
- Is there a representative trait or best, singular measure for fertility?
- What is the distribution of that trait by region? By season/month of calving?
- Is there a genetic trend for seasonal fluctuations in fertility? Is heritability the same for all months/seasons of calving or higher in some seasons?
- Is there a significant sire by season interaction for fertility? Do sires rank differently when seasonal information is included?
- If yes, can we select sires for low seasonal fluctuations in fertility?
- Defining an appropriate model for seasonal/monthly changes in fertility status?
- Are reaction norm models useful in this case?

- Finally, is there a significant sire by region interaction for fertility in the US?

The following three chapters attempted to provide some answers to these questions.

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CHAPTER 3

SEASONALITY OF DAYS OPEN IN US HOLSTEIN[1]

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ABSTRACT

The objectives of this study were to establish a pattern for the seasonality of days open (DO) by state and region within the U.S. and to present statistics on regional trends for DO. Data included 8,676,915 records on DO for Holsteins from 1997 to 2002 covering all regions of the U.S. Fixed effects in the model included herd, parity, milk-class, state × month of calving (MOC), year of calving × MOC and parity × MOC. Least squares means of DO were highest for calvings in March and lowest for calvings in September. Highest mean DO of 155 d was recorded in the Southeast (SE), while the mean DO for the Midwest (MW), Northeast, Northwest and Southwest (SW) were 142 d, 141 d, 140 d, and 137 d, respectively. Variation in monthly averages (VMA) of DO was highest in SE with a range of 51 d, and less than 25 d in all the other regions. Seasonality of calving (SOC) was defined as the ratio of the fewest to the most calvings in months. The SOC was ≥ 60% in SE and ≤ 23% in the other regions. Selected states: TX, OK and AZ in the SW and MO, KS and KY in the MW showed patterns of VMA and SOC similar to those of SE. Distributions of DO were bimodal for some months of calving due to postponed breeding during the hot season or depressed fertility as a result of thermal stress; the second mode at > 200 d was highest in the SE but also could be observed in TX, WI and CA. High level of heat stress for DO exists in the SE and in selected states of the MW and the SW; these regions contribute less than 10% of national records. A methodology for analyzing DO especially under heat stress needs to consider effects of intentionally delayed breeding, for example, by using a model that accounts for bimodality.

Key words: Days open, Heat stress, Seasonality, Month of calving

Introduction

The declining trend in fertility traits in dairy herds over time especially in the Southeastern US has been of growing concern (Silvia, 1998;Wasburn et al., 2002). Reasons for this trend have been largely attributed to the antagonistic relationship between yield and fertility traits (Lucy and Crooker, 2001), which is further exacerbated by high thermal stress suffered during the hot seasons of the year (Wolfenson et al., 2000).

One of the measures of fertility in dairy cattle is days open (DO) — a complex trait that is affected by many factors such as season of calving, management policies, herd size, production level, parity and AI techniques. Even though DO has become accepted as one of the best single measures of reproductive efficiency (Norman et al., 2002), some concerns have been raised about this approach principally because of the large management intervention through deliberate delayed re-breeding, use of bST, and in some instances, no evidence or proof of the results of matings on which DO is based (Weller and Ron, 1992). However, the use of veterinary-confirmed records or using a formula that involves calving interval may help to correct some anomalies connected with the use of DO.

Several studies (Oleggini et al., 2001; Washburn et al., 2002; VanRaden et al., 2002) have reported differences between and within regions in DO, with higher mean DO reported for Southern States of the US. VanRaden et al., (2002) specifically examined the varying trend of DO by month of calving (MOC), whereas the other authors only compared the absolute value of DO by region. The first approach is crucial for genetic evaluations because the performance of animals can be evaluated along a trajectory and the genetic trends for DO can be monitored over time. Also, if monthly fluctuations in DO are due primarily to heat stress, a selection to reduce the fluctuations will increase heat tolerance of animals.

While there were a few studies that looked at the pattern of decline in fertility and reproductive performance in specific states (e.g. Thatcher, 1974 and Cavestany et al., 1985 for FL; Washburn et al., 2002 for States in the South; Silvia, 1998 for KY; Ray et al., 1992 and Stott, 1961 for AZ; Gwazdauskas et al., 1981 for VA; Stevenson et al., 1983 for KS), no study examined the pattern and distribution of heat stress by State across all regions of the US. Such a study would provide a framework for national genetic evaluation for fertility under heat stress. Thus, the objectives of this study were to establish a pattern for the seasonality of DO by State and region within the US and to present statistics on seasonal trends for DO.

Materials and Methods

Data were obtained from the AIPL of the USDA and included 8,676,915 records on 2,375,001 Holstein cows calving between 1997 and 2002. Data covered most States of the US and consisted of multiple parities. Variables in the dataset included herd, days open (DO), calving dates, parity, milk yield and SCC. DO was already computed in the datasets; details of these computations are described by VanRaden et al. (2002). In data editing, DO greater than 20 d and less than 50 d were set to 50 d. DO greater than 365 d were not used in the analyses. Also, parities greater than 5 were not included. Milk Classes were defined as follows: class 1: $\leq$ 8172 kg ; class 2: > 8172 kg and $\leq$ 9534 kg; class 3: > 9534 kg and $\leq$ 10,556 kg; class 4: > 10,556 kg and $\leq$ 11,577 kg; and class 5: > 11,577 kg. Regions used in the analyses were as defined in Figure 1.

Statistical Analyses: Data were analyzed using the General Linear Models procedure of SAS® (1999). The first analysis was done using DO as a dependent variable and the fixed effects of parity, herd, year of calving, milk class and State × MOC and milk class × MOC as independent variables. The second analysis was similar to the first except that State × MOC was replaced by region × MOC effect. In order to generate least squares means by MOC for each State, Proc GLM was run individually on the records for that State. However, for regions, all the records for all the States in that region were pooled. These steps were to facilitate the comparison of the least squares means of DO by MOC between states and between regions. Least squares means of DO by MOC were also generated for parities, year of calving and milk class categories. Seasonality of calving (SOC) was defined as follows: SOC=1-{(Number of calvings in the month with the fewest calvings)/Number of calvings in the month with the most calvings)}. Range of DO was calculated as the difference between the least squares means for DO in the months of calving with the highest and lowest DO. Calculations of both SOC and range were applied to all records for each state and region.

Results and Discussion

Figure 1 presents the assignment of states to regions, and Table 1 shows the distribution of records, number of herds, means and ranges of DO and the SOC by region and states within regions. Additionally, Figures 2 and 3 summarize the information from the table in graphical forms. Means and ranges of DO across seasons were highest for Southeast (SE) while there were small differences in mean DO for Northeast (NE), Northwest (NW) and Midwest (MW). The Southwest had the lowest mean DO (137 d). Within regions, wide DO ranges observed for the SE may imply that the effect of season on mating and calving patterns is more pronounced in this region as compared to other regions. The SOC followed the same trend. Southeastern states had the highest seasonality value of 0.60 while all other regions had SOC values <0.23.

States with high SOC (> 0.50) also recorded wide DO ranges ($\geq$ 42 d). This trend was observed across most regions and may reflect a cause-and-effect relationship. A seasonality of 0.50 implies that about 50% of the cows bred during the hot season calved in the spring. This could be an indication of the effect of either deliberate delayed re-breeding of some cows or low conception rate associated with seasonal thermal stress. Cows for which breeding is delayed or cows with depressed fertility resulting from heat stress necessarily have to have longer DO.

For CA, the pattern of variation of DO by season was unexpectedly small. This state had over two million records (78% of the total records from the SW) and is also noted for large herd sizes. It could be that dairy units are more efficiently managed in terms of improved heat detection procedures, estrus synchronization and prompt AI services. When animals in heat are promptly mated, this compensates for lower fertility in herds of high producing cows (Nebel and McGilliard, 1993; Lucy and Crooker, 2001; Rajala-Schultz and Frazer, 2003).

FL had the smallest range for DO among SE states even though the overall mean DO (159 d) was among the highest in that region. One interpretation for this trend is that in FL, animals are constantly under heat stress and as a result, climatic factors do not fluctuate between extremes when compared to other states (W. W. Thatcher, personal communications).

All states with > 500,000 records (CA, NY, PA, MN and WI) had low SOC (< 0.27) and small DO range (< 25 d) across seasons. These states contribute about 53% of data in this study. In contrast, states with SOC greater than 0.50 and a DO range greater than 36 d (all states of the SE, TX, AZ, KY, DE, OK and MO), contribute only about 8% of records.

Figure 4 presents least squares means of DO for each milk-class category by region. Milk yield classes were included in the model because of the negative genetic correlations between milk yield and reproductive traits reported by several investigators (Hermas et al., 1987; Pryce and Veerkamp, 2001; Washburn et al., 2002). Least squares means for DO increased with milk yield, the largest mean DO was recorded for the highest yielding class (≥ 11,577 kg), and the magnitude of change was similar for all regions. This result could be connected with the antagonistic relationship between yield and fertility/reproductive efficiency as reported by several authors (Seykora and McDaniel, 1983; Nebel and McGilliard, 1993; Faust et al., 1988; Lucy and Crooker, 2001).

Figure 5 shows least squares means of DO for different MOC in the SE, SW, NE, MW and NW. In general, the highest DO were for cows calving in January-March, and the lowest for cows calving in July-September. There are two patterns of variations: large “sinusoidal” and small “dipped”. The last pattern was observed for states with moderate summer climate due to geographical position (e.g., WI), or high altitude (CA, CO, NM). The patterns of variations above may reflect the two extremes; all other states appear to fall into some intermediate categories as indicated by the seasonal ranges of DO (Table1).

Figure 6 presents the distribution of DO in GA for different months of calving. For July-October period, the distribution contains a sharp peak at around 80 d with a slow decline afterwards. Starting in November, a second peak appears at around 280 d. For the next few months, the two peaks move closer, culminating in a single, wide peak for cows calving in April.

Seasonal patterns of monthly DO is, to a large extent due to management decisions of not breeding animals during the hot season because of low fertility during this season (Ingraham et al., 1974; Badinga et al., 1985). For instance, a cow calving in March may be bred in June. If that breeding is unsuccessful, it may be delayed until November. In such a case, the distribution of DO would have a sharp peak corresponding to successful June breeding (circa 90 d), and another peak corresponding to November breeding (240 d).

Figure 7 presents the distribution of DO for cows calving in the months of March and September for TX, a state with high SOC, CA and WI, which are states with low SOC. The distribution for March calvings is bimodal also for these states. However, the height of the second peak is smaller in CA or WI than in TX**,** perhaps due to unsuccessful inseminations, rather than delayed re-breeding. In contrast, September calvings for all three states show a long right tail and no double peaks. Thus, delayed breeding or depressed fertility due to seasonal factors seems to occur in many states although at different levels. Also, there is a growing perception by some herd owners that deliberate delayed breeding is a viable management and economic strategy in modern dairy management (Arbel et al., 2001; Washburn et al., 2002; Rajala-Schultz and Frazer, 2003). Thus, large DO may be due to delayed breeding and not necessarily be an indication of poor fertility.

Use of DO as an indicator of fertility in genetic evaluations may require a more sophisticated analysis. While very short DO indicate good fertility, large DO may be due to poor fertility or to delayed breeding or poor heat detection. If a majority of cows cycle within 80 d and get pregnant within four cycles (of 21 d), legitimate DO would be limited to about ≤ 164 d. Records with larger DO could be considered outliers and edited out. In another procedure, each record would be assigned the probability of being due to delayed/non-delayed breeding, e.g., based on month of calving, location and DO. Subsequent analysis would consider the two groups of records as being generated from a mixture distribution (McLachlan and Ped, 2000). The status delayed/non-delayed can be determined accurately for cows for which all insemination records are available. In addition, the use of actual estrus detection records would also facilitate the above process.

Conclusions

Days open is a complex trait that is influenced by regional and seasonal factors. Heat stress in the form of seasonal breeding and high variations of days open is mostly present in the Southeast, parts of the Southwest and Midwest. Long days open records do not necessarily reflect poor fertility, since they could also be result of sound management decisions. It is recommended that potential genetic evaluations for days open as a fertility trait should consider those decisions, e.g., by including additional information or by a sophisticated statistical model.

Acknowledgements

Data was provided by the AIPL of the USDA. Dr. Paul VanRaden and Melvin Tooker provided insight about the data structure and formats. Jarmila Bohmanova assisted with some of the charts. We acknowledge useful discussions with Drs. B. Graves and J. West. Finally, we acknowledge the financial support from the USDA grant No 2001-5101-11318.

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Table 3.1. Seasonality of calving, means and ranges of days open (DO) by region.

States Region[3]	Number of records	Number of herds	Seasonality of calving[1]	Mean DO	Range of DO[2]
GA	50,759	142	0.64	156	52
FL	48,318	92	0.51	159	36
NC	70,057	134	0.52	155	47
SC	27,123	64	0.65	152	63
TN	48,091	137	0.60	155	54
AR	8655	74	0.70	154	61
AL	13,068	42	0.74	152	64
LA	20,815	120	0.78	153	69
MS	20,018	71	0.74	155	67
All SE	**306,905**	**382**	**0.60**	**155**	**51**
CA	2,251,374	764	0.27	135	17
CO	85,838	79	0.18	148	17
NM	80,554	38	0.17	134	16
NV	24,513	22	0.29	143	21
OK	23,401	100	0.61	157	49
TX	176,853	271	0.51	150	47
UT	100,292	213	0.26	147	15
AZ	140,052	58	0.60	134	39
All SW	**2,660,103**	**987**	**0.23**	**137**	**18**
VT	123,846	496	0.26	137	24
VA	179,029	313	0.41	146	37
RI	774	6	0.55	145	41
PA	769,777	2468	0.23	141	25
CT	35,794	122	0.24	140	26
DE	12,248	35	0.55	151	44
MA	29,506	130	0.26	142	26
MD	118,252	383	0.36	147	30
ME	37,630	160	0.24	141	23
NH	30,339	110	0.27	140	32
NJ	21,573	110	0.31	149	32
NY	516,732	1278	0.27	138	21
All NE	**2,153,012**	**2755**	**0.23**	**141**	**25**
ID	175,516	214	0.28	138	17
MT	20,468	66	0.42	141	13
OR	103,267	188	0.20	142	13
WA	216,068	235	0.21	141	15
WY	1863	10	0.71	135	25
All NW	**517,171**	**489**	**0.22**	**140**	**14**
IA	204,542	784	0.22	147	26
IL	108,337	402	0.37	153	34
IN	91,000	361	0.33	149	32
KS	65,530	191	0.44	154	45
KY	39,588	185	0.57	154	42
MI	290,107	820	0.29	142	23
MN	762,387	1847	0.20	143	23
MO	61,664	303	0.55	152	47
ND	15,003	71	0.34	148	28
SD	40,472	182	0.20	151	26
NE	55,744	165	0.25	153	30
OH	251,154	703	0.29	146	24
WI	1,036,166	2153	0.22	134	18
WV	148,094	67	0.33	148	31
All MW	**3,039,724**	**2801**	**0.21**	**142**	**24**
All States	8,676,915	5645	0.30	142	25

[1] Seasonality of calving = (minimum number of calvings in a month) / (maximum number of calvings in a month).

[2] Range = difference between max and min DO.

[3] SE = Southeast, SW = Southwest, NE = Northeast, NW = Northwest, and MW = Midwest.

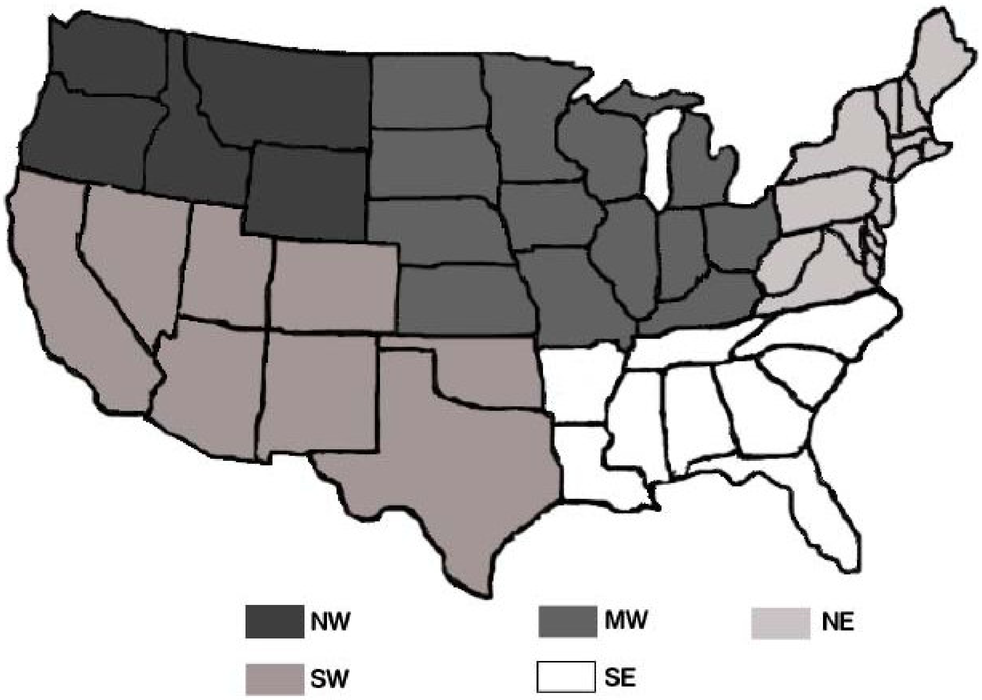


Figure 3.1. Map of the USA showing the distribution of States by region: Southeast (**SE**); Southwest **(SW)**; Northeast (**NE**); Northwest (**NW**); Midwest (**MW**).

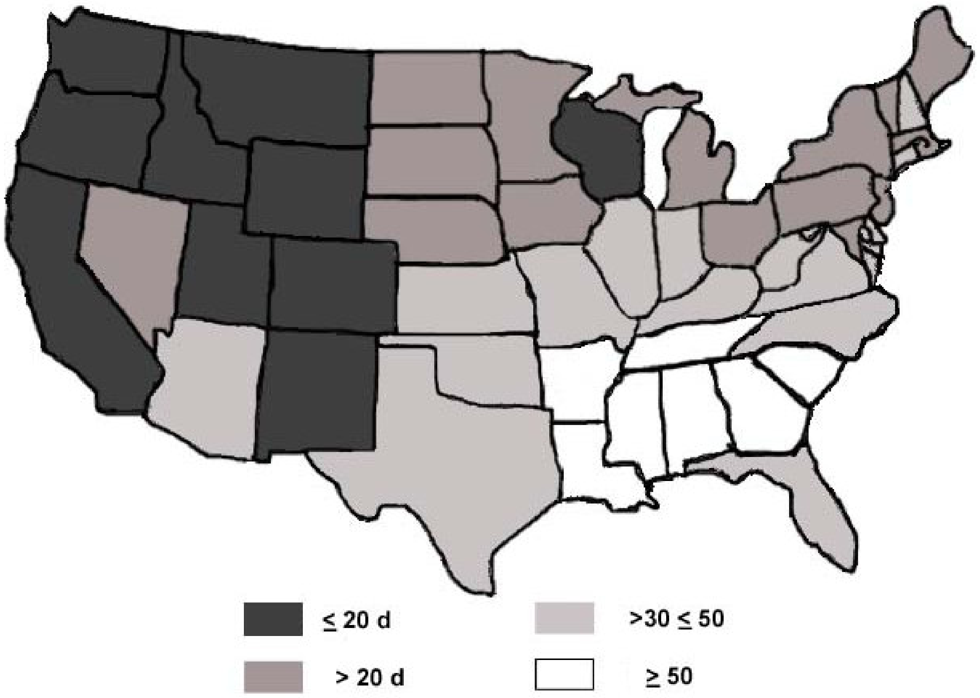


Figure 3.2. Distribution of states by ranges of days open.

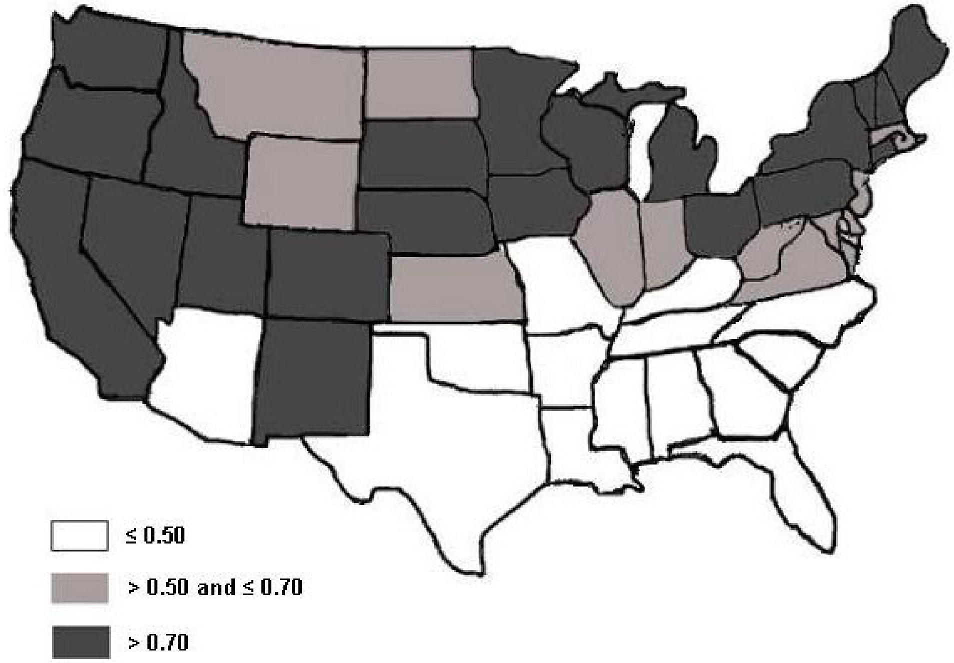


Figure 3.3. Distribution of states by seasonality of calving.

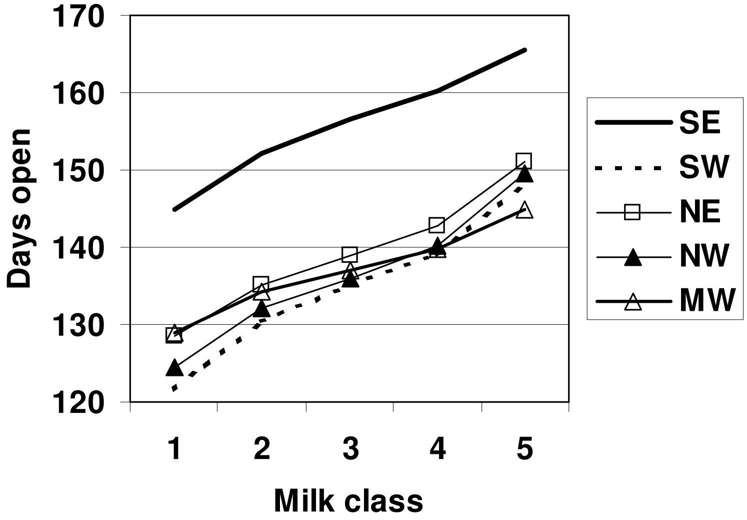
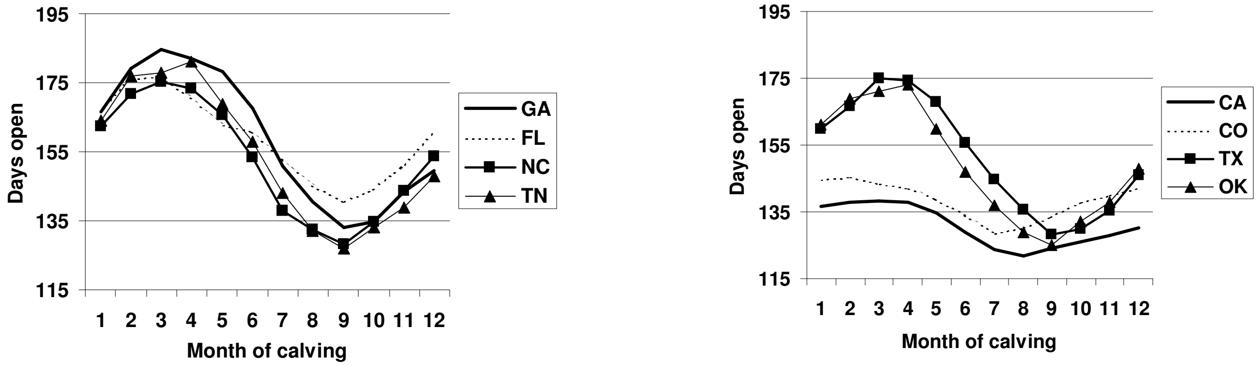
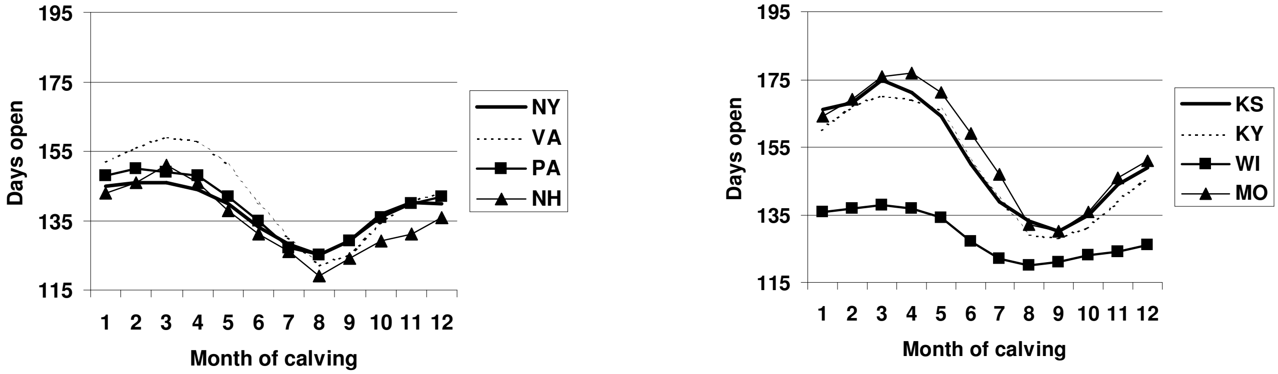


Figure 3.4. Least squares means of days open by milk classes for five regions: Southeast (SE); Southwest (SW); Northeast (NE); Northwest (NW); Midwest (MW).


a) GA, FL,NC,TN

b) CA,CO,TX,OK


c) NY,PA,VA,NHd) WI,MO,KS,KY

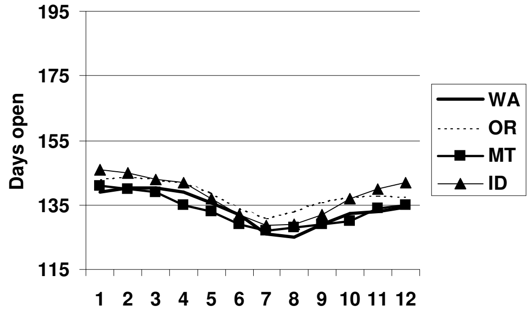

e) WA,ID,MT,OR

Figure 3.5. Least squares means for days open by region: a) Southeast (GA, FL, TN and NC); b) Southwest (CA, CO, OK and TX); c) Northeast (NY, PA, NH and VA)**;** d) Midwest (WI, MO, KY and KS); e) Northwest (WA, OR, MT and ID).

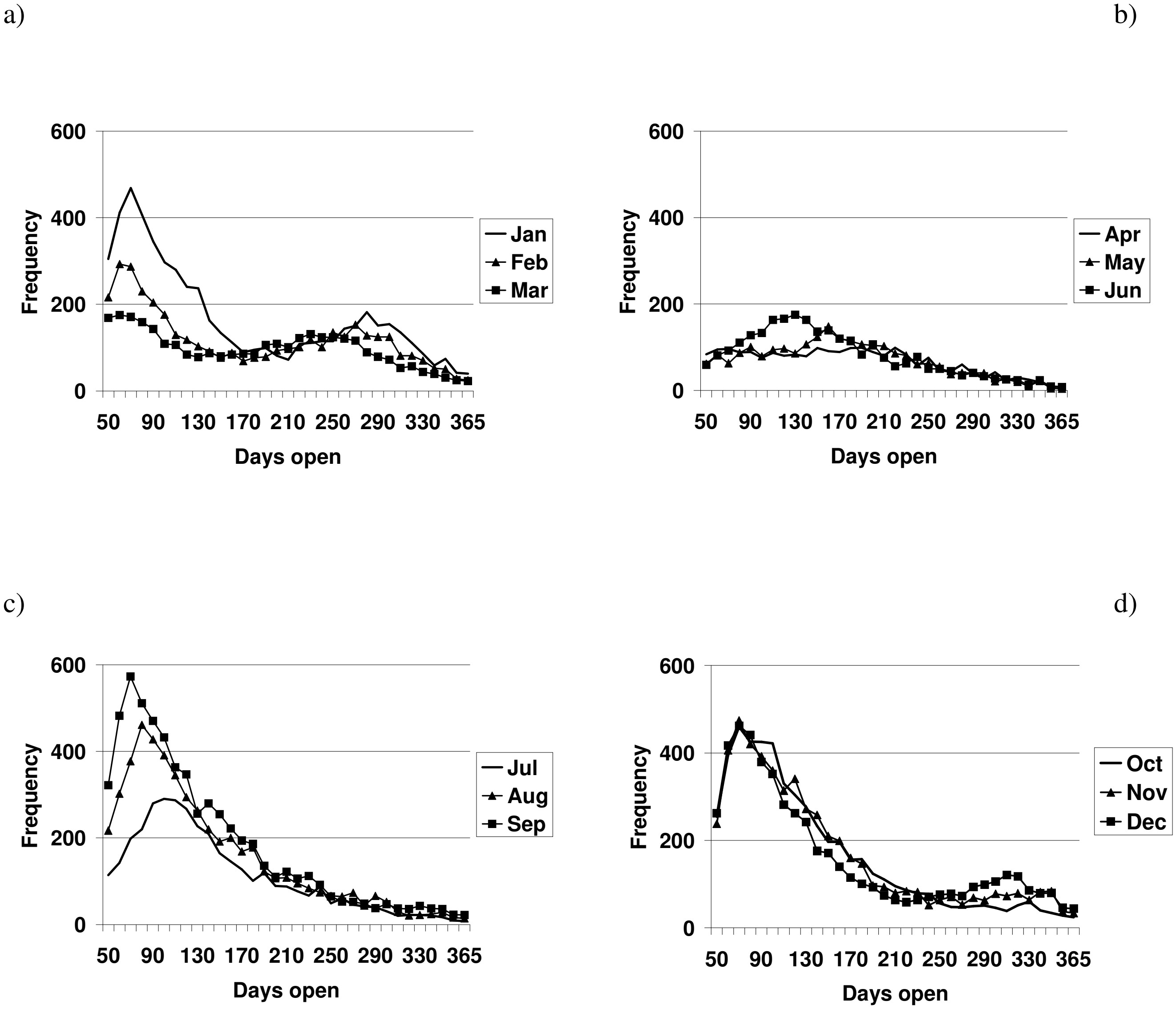


Figure 3.6. Distribution of days open in GA by month of calving: a) January – March; b) April – June; c) July – September; d) October – December.

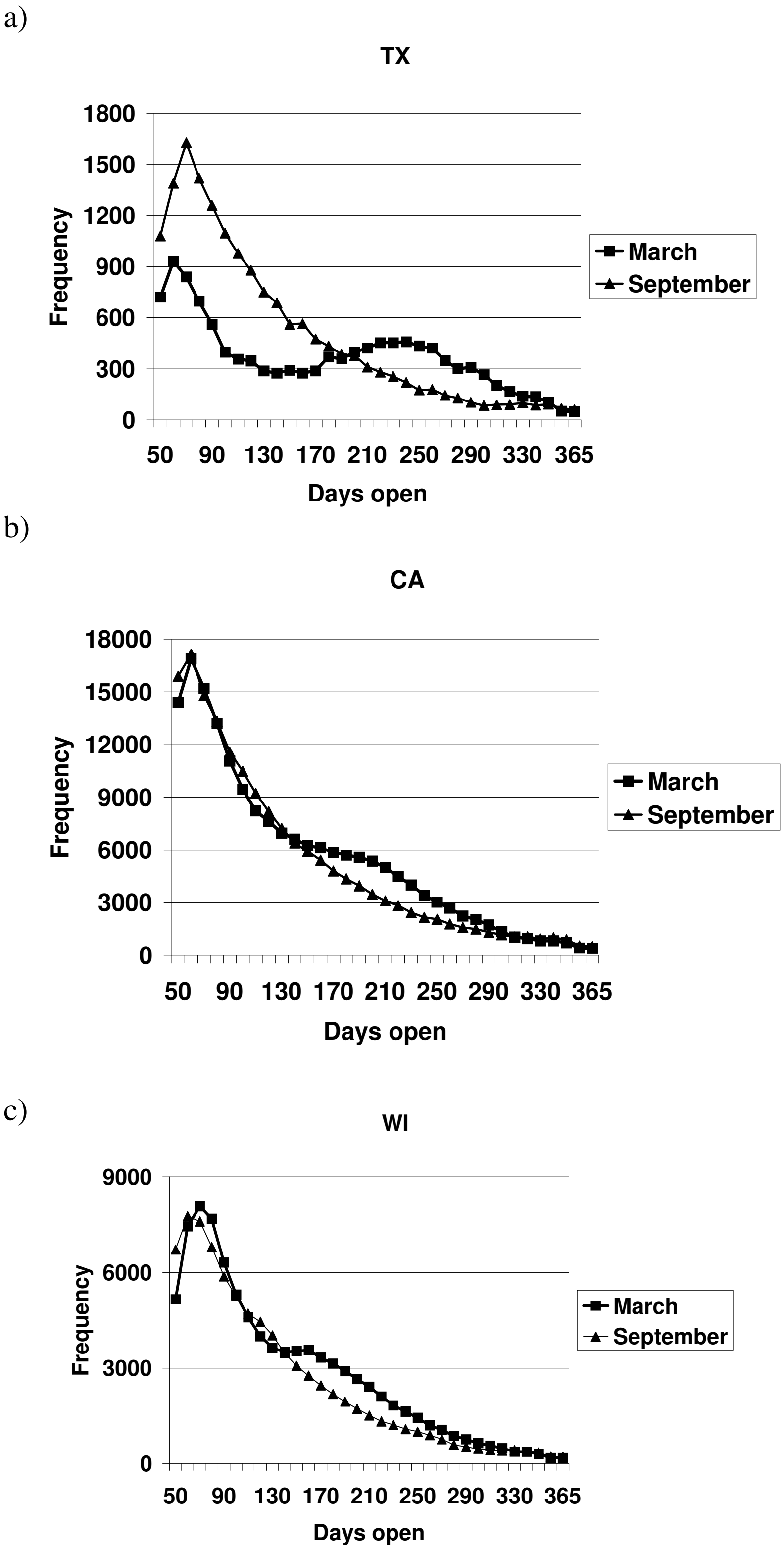


Figure 3.7. Distribution of days open for March and September calvings: a) TX; b) CA; c) WI.

CHAPTER 4

GENETIC PARAMETERS FOR DAYS OPEN AND PREGNANCY RATE FOR US HOLSTEINS USING DIFFERENT EDITING CRITERIA[1]

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[1] Oseni, S., I, Misztal, S. Tsuruta, and R. Rekaya. Submitted to Journal of Dairy Science 04-13-04

ABSTRACT

The influence of different editing of days open (DO) records on the genetic parameters of DO and pregnancy rates (PR) in US Holsteins was investigated. Data included first parity 305-d milk yield and DO records in eight states: GA, FL, NC, TX, AZ, CA, NY, and WI. Pregnancy rate was computed as 1/[(DO–X)/HI+1)], where X was the approximate voluntary waiting period, and HI was the heat interval set to 21 d. Upper limit for PR was set to 1.0. A bivariate animal model for DO (or PR) and 305-d milk yield was fit separately for each state. The model included fixed effects of herd-year, month of calving and age of cow, and random animal and residual effects. In separate analyses, large DO records were limited to 150, 200, 250, 300 and 365 d. Additionally, analyses for PR used values of 50, 80 and 120 d for X. PR assigns more weight to small DO records, and larger heritability for PR indicates larger contributions of such records. Large changes in heritability when an interval was limited indicated genetic variability within that interval. Genetic and residual variances for DO were strongly dependent on the upper limit, with both variances changing up to 8 times as DO upper bound increased from 150 d to 365 d. Estimates of heritability for DO varied between 3 and 6 %. There was a 30% increase in heritability estimate as the upper limit increased from 150 –d to 250 –d for FL and NC, and smaller to flat for the other states. The increase from 250 to 365 caused small or no changes. The genetic correlation between milk and DO was the highest for FL (0.6) and the smallest for GA (0.12 - 0.23). For PR with X=50, the heritability was higher than the corresponding estimate for DO in GA, equal for AZ, and smaller for the remaining states. Also for PR, heritabilities varied by the length of X; for some states (GA and AZ), highest heritabilities were obtained at X=50 d; for NY and WI, it was at X=80 d and at X=120 d for FL, NC and CA. Records of DO > 250 d carry little genetic information whereas records < 120 d carry more or less information

depending on management. Days open and PR are strongly influenced by differences in management protocols between states.

Key Words: Days open, Pregnancy rate, Voluntary waiting period, Genetic parameters

Introduction

Days open (DO) has been analyzed routinely in the genetic evaluations of dairy cows for fertility (Makuza and McDaniel, 1996; Thaller, 1997; Norman et al.; 2002; VanRaden et al., 2003). However, there is no consensus among authors as to editing criteria for this trait. The AIPL/USDA uses an upper limit of 250 d (VanRaden et al., 2003) whereas others (Hoeschele, 1991; Seykora and McDaniel, 1983; Hansen et al., 1983a; Fuerst and Sölkner, 1994; Dematawewa and Berger, 1998; Abdallah and McDaniel, 2000; Oseni et al. 2003) have used various DO editing by data truncation (whereby DO records greater than a certain threshold are edited) or by setting upper limits (where DO records beyond a certain limit are set to that limit). Thresholds used included 150 d, 250 d, 300 d, 305 d, 310 d, 365 d, 450 d and 701 d.

Several authors (Janson and Andreasson, 1981; Butler and Smith, 1989) have argued that interval traits like DO and calving interval (CI) are not good measures of cow fertility because of large influence of management through preferential husbandry. The breeding of cows can be intentionally delayed due to high yield, bST use, embryo transfer or seasonal factors (Luna-Dominguez et al. 2000; Rajala-Schultz and Fraser, 2003). Arbel et al., (2001) examined the profitability potentials in extended DO and CI in Israeli herds and presented evidence indicating that high producing herds can be allowed a longer voluntary waiting period (VWP) (150 d for primiparous cows and 120 d for multiparous cows) without compromising profitability. Thus, the inclusion of records with long DO may give biased estimates of genetic parameters for DO and may introduce biases in sire evaluations for fertility (Seykora and McDaniel, 1983). However, elimination of such records may lead to the editing of data on infertile animals – the primary target group for genetic evaluations. A compromise used by USDA/AIPL (VanRaden et al., 2003) is by setting limits, where DO over a certain age (or open cows) are assigned a limit or bound. Thus, large residual variance caused by prolonged DO records is restricted so that the proportion of total variance due to additive genetic variance is increased.

Management of reproduction may be different in different states. Norman et al., (2002) identified VWP between calving and first breeding, use of bST and designed reproductive programs as some key management factors which may impact genetic evaluations for DO. Also, Oseni et al. (2003) have shown that parameters of DO such as mean and SD varied by state and season of calving. In some cases, the distribution of DO was bimodal indicating delayed breeding due to summer heat stress. If breeding is delayed due to hot weather, prolonged DO would not only be due to low fertility but also due to management, and heritability estimates with records with large DO limit will be lower. If breeding for productive cows is delayed, heritability assuming low VWP would be lower.

Days open as a fertility trait puts a large emphasis on long DO records. In contrast, pregnancy rate (PR), which can be derived approximately as a function of DO, puts a large emphasis on short DO records. There is a question regarding which of these is more useful for genetic improvement of fertility. One useful indicator would be higher heritability. The purpose of this paper was to examine the effect of different upper limits and length of the VWP on genetic parameters of DO and PR in selected states in the USA. States included are those with high level of heat stress and at least moderate presence of dairying, and some selected major states in dairy production.

Materials and methods

Fertility data on first parity calvings of Holstein cows for eight states (GA, FL, NC, CA, TX, WI, NY and AZ) were extracted from the master file of the AIPL/ USDA. These datasets covered all states of the US over a period of six years (1997 – 2002). Data editing included setting records greater than 21 days and less than 50 days to 50 days. Sub-sets of the data for each state were created by setting upper limits to DO at 150 d, 200 d, 250 d, 300 d and 365 d. By setting upper limits, records greater than a specific threshold were set to that threshold. CA, WI and NY had large datasets (over one million records each). For these three states, first parity records of the original datasets were randomly sampled by herd in order to reduce computing. PR was defined as follows:

PR = 1/[(DO-VWP)/HI +1] where VWP = approximate VWP (set at 50 d) and HI = heat interval (set at 21 days). The summary of the datasets after editing is shown in Tables 1 and 2 for DO and PR, respectively. Sub-sets of the data for each state were created at different VWP of 50 d, 80 d and 120 d.

Models: A bivariate animal model, with DO (or PR) and 305-d milk yield was fit as follows:

$$\mathbf{y_{ijklmt} = hy_{it} + moc_{jt} + age_{kt} + a_{lt} + e_{ijklmt}}$$

where y_{ijklmt} is DO or PR (t=1) and first lactation 305-d milk yield (t = 2) for animal l in the age class k (k=1,5), calving in month j (j=1,12) in the herd-year (hy_{it}) class i; moc_{jt} = fixed effect of the month of calving j; a_{lt} = random effect of the animal l and e_{ijklmt} = random error associated with each observation. Animal and residual effects for both traits were assumed correlated.

(Co)variance components were estimated using the Average Information REML procedure via AIREMLF90 (Misztal et al., 2002).

Results and discussion

<u>Phenotypic means and standard deviations for DO and PR</u>

Tables 1 and 2 show the means and standard deviations for DO and PR across five upper bounds respectively. Means for DO increased by 25 to 50% as DO upper limit increased from 150 d to 365 d. Mean DO for FL was the highest across all the thresholds, followed by the mean for GA; means for TX and NC were intermediate and higher than the means for AZ, CA, NY, and WI which were all markedly similar. These rankings were mostly maintained across all thresholds. Mean DO of 153 d and 169 d reported by Dematawewa and Berger (1998) and Abdallah and McDaniel (2000) for IA and NC herds respectively, fall within the range of mean DO at the 300 d limit in the current study. Also, across most upper bounds, standard deviations were smaller for WI, NY and AZ data, suggesting that herd management for DO may be more consistent for herds in these states than in the other states.

In contrast to DO, the means for PR (Table 2) decreased with increasing DO thresholds because PR puts small weights on long DO records. Highest PR means were for WI and CA (34% and 35%), and the lowest were for FL and GA (25% and 27%). Several authors (Slama et al., 1976; Washburn et al., 2002) attributed major sources of variation in DO and other interval traits to conception rate, level of milk yield, seasonal and environmental factors, age of cow and service sire. Also, differences exist between herds in estrus detection, percentage of missed heats and reproductive management protocols, all of which are known to affect herd fertility levels.

Variance components and heritability

Figures 1 and 2 present the residual variance (VE) at different upper bounds for DO and PR respectively. Residual variances for DO showed a steady increase (4 to 8 times) from the 150 -d up to 365 -d upper limit. At the 150 -d thresholds, estimates of VE ranged from 982 for FL to 1,289 for CA. Hoeschele (1991) reported a VE of 1041 for DO at the 150 -d bound for a combined dataset from several states in Southeastern USA. Similarly, Residual variance of 6265 reported by Dematawewa and Berger (1998) for upper limit DO of 305 -d falls within the range of VE for the 300 -d upper limit in the current study. It is, however, lower than the estimate of 9981 reported by Campos et al. (1994) for FL herds. Among states, there were small differences for residual variances at the 150 -d and 200 -d bounds. However, larger differences are seen at higher DO thresholds ($\geq$ 250 d), with higher estimates for the southeastern states – GA, NC, FL - and TX. In contrast to DO, VE for PR (figure2) showed very slight differences (12 to 22%) across thresholds, indicating that PR is less affected by different limits when compared to DO.

Additive genetic variance (VA) for DO (Figure 3) increased up to 8 times between the lowest and highest DO upper bounds. Patterns of fluctuations across different upper bounds were similar among states, except for FL. The range of VA at the 150 d threshold was 34 (NC) to 67 (CA), which were higher than estimates of 22.6 reported by Hoeschele (1991) for genetic variance for DO at the 150 d upper bound using a sire model. However, the estimate of 277.5 reported by Dematawewa and Berger (1998, IA data) was within the ranges of VA in the current study, while the estimate of 549 (Campos et al. 1994, FL data) was outside the ranges at the 300 –d bound. For PR, (Figure 4), smaller changes in VA (approximately 40%) across DO thresholds were observed, a trend similar to the VE patterns for PR. Smaller variations in PR is due to low weight for records with long DO.

Heritability estimates for DO (Figure 5) ranged between 3.0% and 6.3%. For some states (FL, NC, WI and NY), estimates of heritability were lower at DO thresholds ≤200 d while for others, estimates were relatively constant across all thresholds. This could be due to large content of genetics in records of DO in the range of 150 – 200, which could be due to large VWP associated with high production (WI, NY) or low fertility at low VWP (FL, NC). Also, heritability estimates were similar at higher thresholds (≥ 250 d). Variations within large DO thresholds could be due to management than to genetics. Hoeschele (1991) reported no difference between heritability estimates for two DO upper bounds of 150 d and 305 d. The fact that fertility deteriorated over time could help to account for differences in the literature (Washburn et al., 2002). However, the range of heritability estimates for DO for all states across all DO bounds agree with the estimates of 2% - 6% in the literature for DO and other interval traits (Hansen et al., 1983a,b; Hayes et al., 1992; Martl and Funk (1994) for WI herds; Van Arendonk et al., 1989; Poso and Mantysaari, 1996; Dematawewa and Berger, 1998; VanRaden et al., 2002).

Heritability estimates for PR at VWP = 50 d (Figure 6) were lower than the corresponding estimates for DO for most states (FL, NC, WI, TX, CA, NY), slightly higher for GA, and not different for AZ. Days open as a fertility measure puts more emphasis on later records, in contrast to PR which puts more weight on earlier records. The calculation of PR assumed VWP of 50 d. In reality, VWP varies across herds and has been identified by Norman et al. (2002) as one of the management factors affecting genetic parameters for DO. No records or information on the length of the VWP were available. Voluntary waiting period can be partially ascertained through analyses of within farm records. However, the length of the VWP may vary for cow groups within farm due to production level, cull prices, season, etc. (B. Cassell and R. Pearson, 2003. Personal communication) .

Table 3 shows estimates of heritability for PR at different assumed VWPs of 50 d, 80 d and 120 d. For GA and AZ, the highest heritability was for VWP=50 d and it was higher than the estimate for DO. In states with seasonal heat stress, the length of VWP during the cooler season may be short, in order to maximize chances that cows are successfully bred before the onset of seasonal heat stress. Higher heritability for PR than for DO suggest that important genetic differences for some states occurred in animals with low rather than high DO. For CA and FL, the highest heritability was at VWP=120 d. This suggests that variability with DO < 120 d contained little genetic variation and could probably be ignored. For these states, also, heritability for DO was always higher than for PR. This suggests that records with large DO, which received minimal weight under PR, contained substantial genetic information. High VWP could be due to greater profitability at higher VWP when fertility is adequate (CA) or due to low conception rates at short VWP, particularly under constant heat stress (FL). These varied trends of PR with changing VWP agree with the report of Norman et al. (2002) that the length of the VWP was a management factor in the genetic evaluation of dairy cattle for fertility. Differences between states in the genetic parameters for PR could also be due to differences in heat detection (Dransfield et al., 1998; Washburn et al., 2002). These authors noted that in many herds, > 50% heats are undetected. Factors omitted in this study were differences between herds in reproductive management protocols (estrous synchronization, timed AI, etc). Goodling et al., (2003) showed that heritability estimates for days to first breeding were higher for synchronized cows than for non-synchronized herds (8.0% Vs 5.3% respectively).

In most states, heritability for PR increased at thresholds > 200 d while differences in heritability estimates were minimal or non-existent for thresholds beyond 250 d. Also, for PR, highest heritability were at VWP = 120 d. Consequently, records of DO can be limited in the range of 120 – 250 d or perhaps even 120 – 200 d, without lowering heritability estimates. If lower and upper limits or thresholds can be set to most DO records, then this trait will be close to binary, where the first category is "pregnant before the lower limit" and the second is "not pregnant" by the upper limit.

Genetic and phenotypic correlations between DO and milk

Estimates of genetic correlations between DO (PR) and 305 -d milk yield are shown in Figure 7 (Figure 8). Estimates were relatively constant across DO upper limits within states, indicating that genetic correlations between DO and 305 –d milk were unaffected by DO thresholds. However, most of the estimates were moderately antagonistic for most states and highly antagonistic for FL in agreement with reports in the literature (Hansen et al., 1983a; Short et al., 1990; Campos et al., 1994). These estimates may imply preferential husbandry in many states, suggesting that the production level could play a major role in determining when to re-breed cows. Philipsson (1981) described such genetic correlations as 'forced' since they may have resulted from the intentional delay of some cows based on the level of milk yield. Alternatively, such moderate genetic correlations may indicate true genetic antagonisms between DO and milk yield - a phenomenon whereby a cow's energy resources are channeled towards milk production, leading to the suppression of reproduction functions, in agreement with several studies (Seykora and McDaniel, 1983; Hermas et al., 1987; Pryce and Veerkamp, 2001).

Estimates of phenotypic correlations between DO and 305 –d milk yield (and PR vs 305 –d milk) at different DO thresholds are shown in Tables 4 and 5 respectively. These correlations were generally low (≤ 0.13 for DO and ≥ -0.14 for PR), and relatively constant across all DO upper bounds within states. Reports by several authors (Hansen et al., 1983a, Van Arendonk et al., 1989; VanRaden et al., 2003) also indicated low phenotypic correlations between DO and milk yield. Genetic correlations were in general, higher than the corresponding phenotypic correlations, as found in other reports (Hansen et al., 1983a; Hoekstra et al., 1994; Pryce et al., 1997).

Conclusions

Upper limits on DO affected states differently, reflecting the large influence of environmental and management practices on the estimates of genetic parameters across states. Estimates of variance components are more stable for PR than for DO. Differences between states in genetic parameters for PR depend strongly on the assumed length of the VWP. Genetic variations in DO upper bounds > 250 d is minimal and records of DO can be limited to 250 d. Genetic correlations between DO (or PR) and 305 –d milk yield are antagonistic, with genetic correlations strongly dependent on the state. Days open and PR can be analyzed more accurately when information on management of fertility such as length of the VWP, service period, estrous synchronization, and bST are available.

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Table 4.1. Means and standard deviations of days open (DO) across different upper bounds.

		DO150		**DO200**		**DO250**		**DO300**		**DO365**	
State	**N***	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
GA	21,484	120	36	139	55	154	72	164	87	172	101
FL	20,528	123	34	145	54	161	72	173	88	183	104
NC	28,240	119	36	138	55	151	71	159	84	166	96
TX	70,158	117	37	135	56	149	73	158	87	166	100
CA	49,056	108	38	121	55	130	68	135	79	140	89
WI	42,757	109	37	121	52	128	64	132	73	135	80
AZ	49,548	112	35	125	51	132	64	137	73	140	81
NY	36,307	111	36	124	53	132	65	136	74	139	82

n* = number of records

Table 4.2. Means* and standard deviations of pregnancy rates* (%) across different upper bounds

		DO150		DO200		DO250		DO300		DO365	
State	**n****	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**
GA	21,484	31	21	29	23	28	23	28	24	27	24
FL	20,528	29	20	27	21	26	22	25	22	25	22
NC	28,240	31	22	29	24	29	24	28	24	28	25
TX	70,158	32	23	31	24	30	25	30	25	29	25
CA	49,056	37	25	36	27	36	27	36	27	35	27
WI	42,757	36	24	35	25	35	25	34	25	34	26
AZ	49,548	33	22	32	23	32	22	32	23	31	23
NY	36,307	34	22	33	23	33	24	33	24	32	24

*voluntary waiting period = 50 d

**n = number of records

Table 4.3. Estimates of heritabilities (%) for pregnancy rates* at different voluntary waiting periods (VWP).

State	**DO150**			**DO250**			**D0365**		
	Vwp50	**vwp80**	**vwp120**	**vwp50**	**vwp80**	**vwp120**	**vwp50**	**vwp80**	**vwp120**
GA	4.1	3.2	2.7	4.4	3.5	2.9	4.5	3.6	3.0
FL	2.9	3.5	4.8	3.7	4.3	5.6	4.1	4.6	5.7
NC	2.3	2.5	2.6	2.8	3.0	3.3	2.9	3.1	3.5
TX	3.0	3.1	3.0	3.2	3.3	3.2	3.3	3.4	3.3
CA	4.0	4.2	4.8	4.3	4.5	5.0	4.4	4.5	5.0
WI	2.9	3.3	2.5	3.1	3.3	3.0	3.3	3.4	3.1
AZ	5.0	4.7	3.8	5.2	5.0	4.2	5.4	5.0	4.3
NY	2.9	3.3	2.7	3.2	3.6	3.2	3.4	3.7	3.3

*estimates based on VWP = 50 d
DO150, DO250, DO365 = days open at 150, 250, 365 d upper limits respectively.

Table 4.4. Phenotypic correlations between 305-d milk yield and days open (DO) at different DO threshold by state.

State	DO150	DO200	DO250	DO30	DO365
GA	0.13	0.12	0.12	0.13	0.13
FL	0.13	0.12	0.12	0.11	0.12
NC	0.09	0.09	0.09	0.10	0.10
TX	0.07	0.06	0.06	0.06	0.06
CA	0.12	0.12	0.12	0.13	0.13
WI	0.04	0.05	0.06	0.07	0.07
AZ	0.11	0.11	0.10	0.10	0.10
NY	0.10	0.10	0.11	0.11	0.11

Table 4.5. Phenotypic correlations between 305-d milk yield and pregnancy rates at different days open (DO) threshold by state.

State	**DO150**	**DO200**	**DO250**	**DO300**	**DO365**
GA	-0.13	-0.13	-0.13	-0.13	-0.13
FL	-0.14	-0.14	-0.14	-0.14	-0.14
NC	-0.10	-0.10	-0.10	-0.10	-0.10
TX	-0 .07	-0.07	-0.07	-0.07	-0.07
CA	-0.11	-0.12	-0.12	-0.12	-0.12
WI	-0.03	-0.03	-0.04	-0.04	-0.04
AZ	-0.11	-0.11	-0.11	-0.11	-0.11
NY	-0.10	-0.10	-0.10	-0.10	-0.10

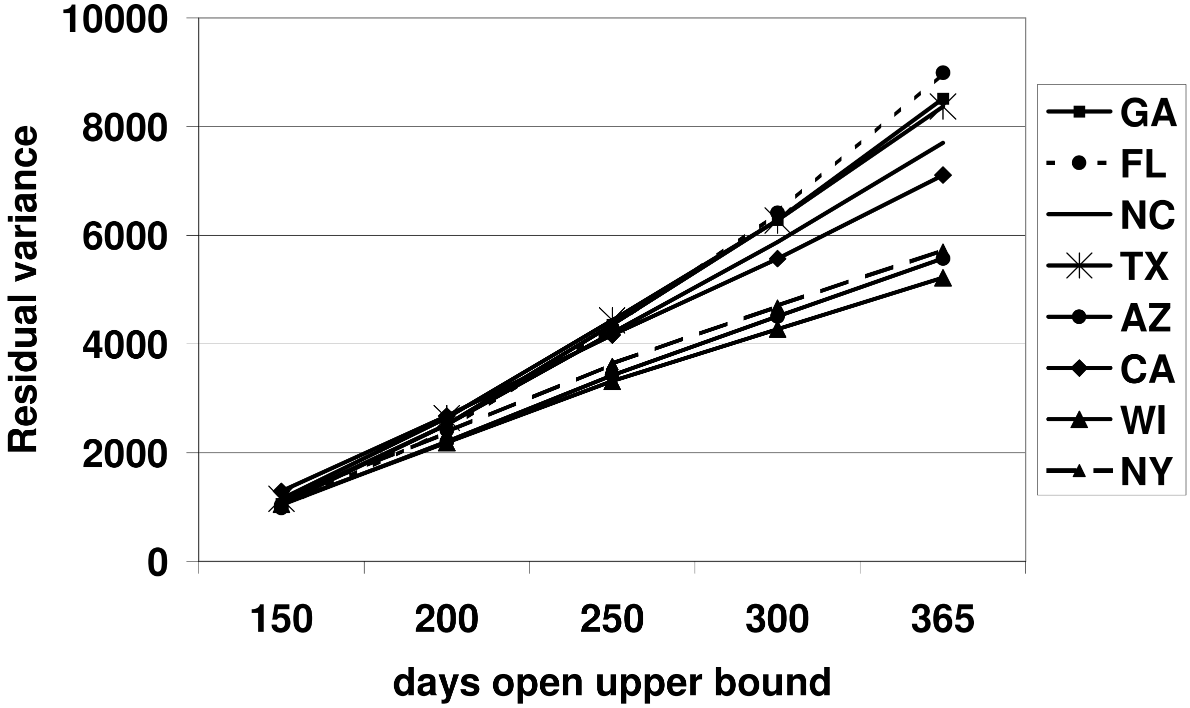

Figure 4.1: Residual variances for days open across different upper bounds.

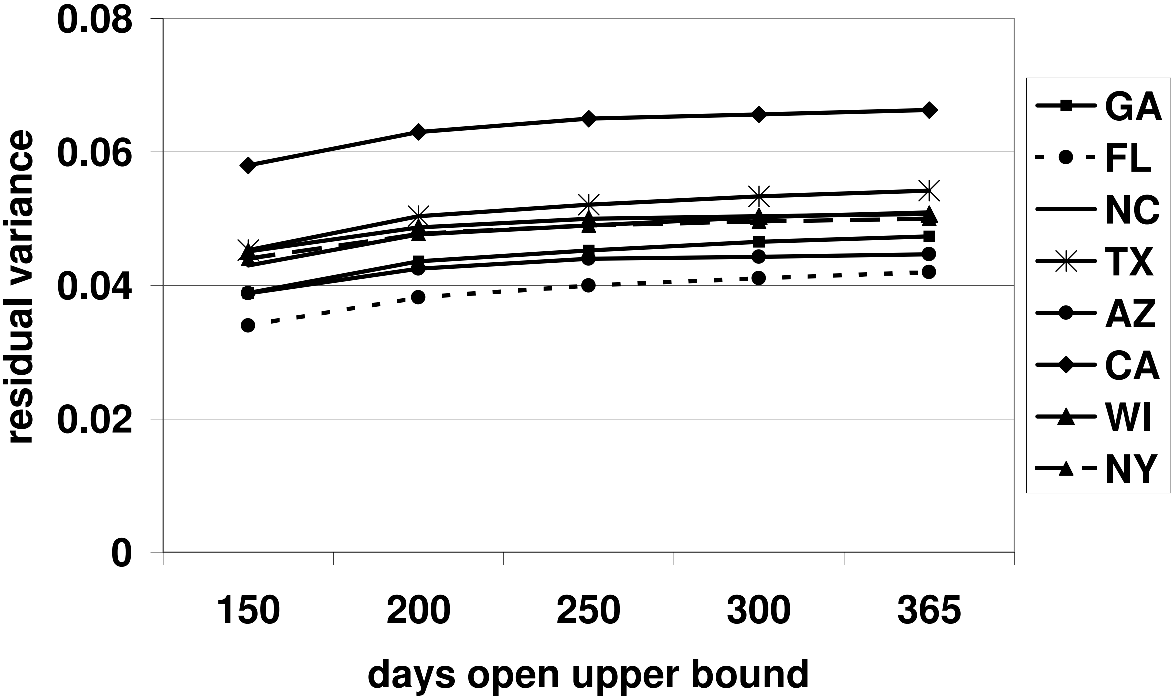

Figure 4.2: Residual variances for PR across different days open thresholds for eight states

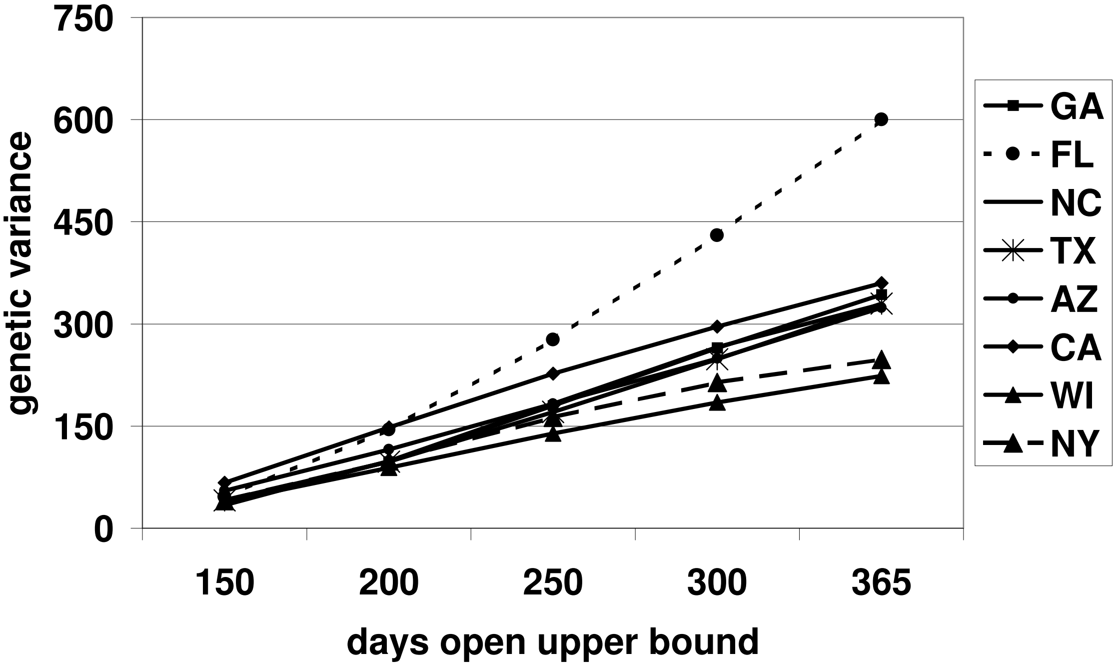

Figure 4.3. Additive genetic variances for DO across different upper bounds.

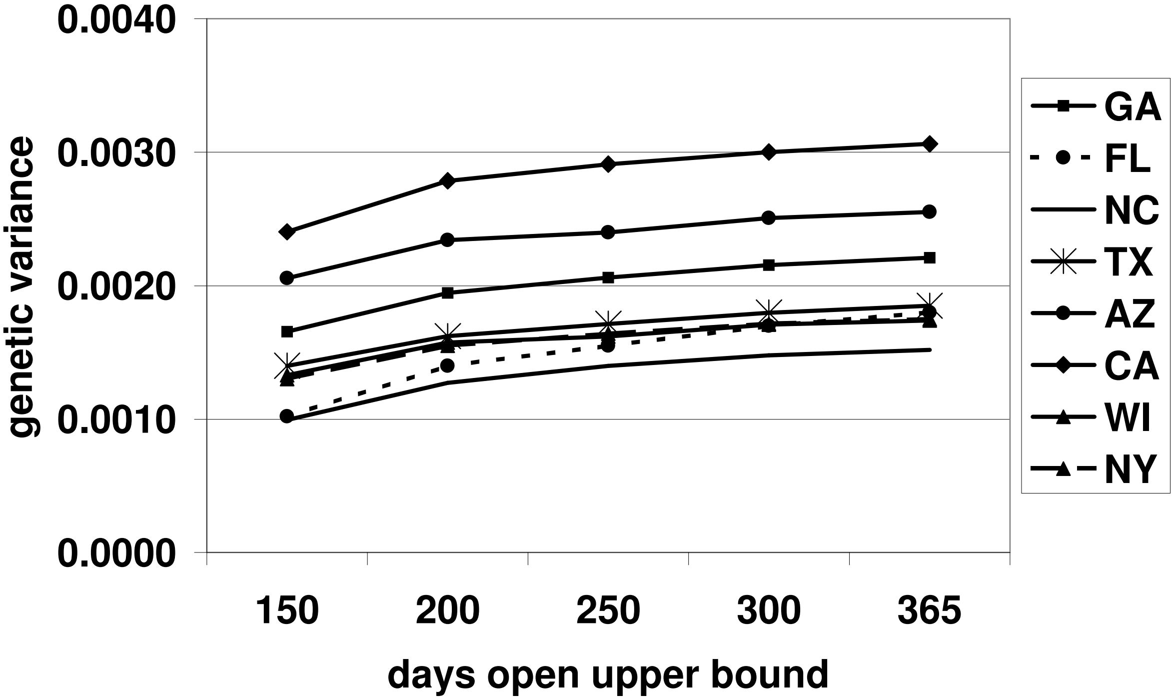

Figure 4.4. Additive genetic variances for pregnancy rate across different DO upper bounds

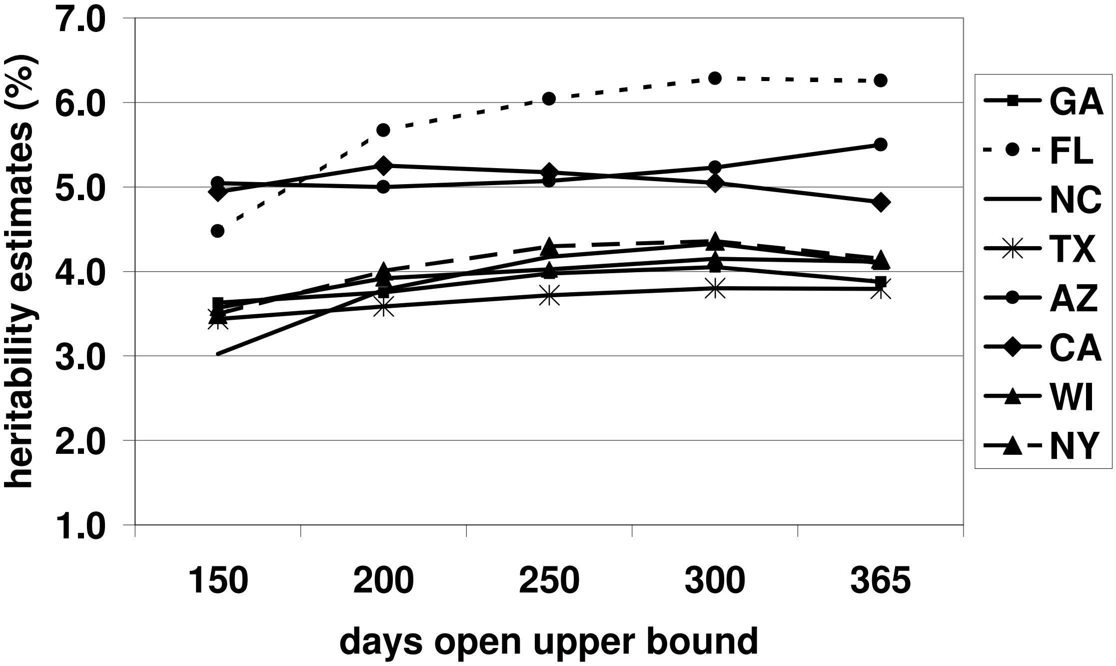

Figure 4.5. Heritability estimates for days open across different upper bounds.

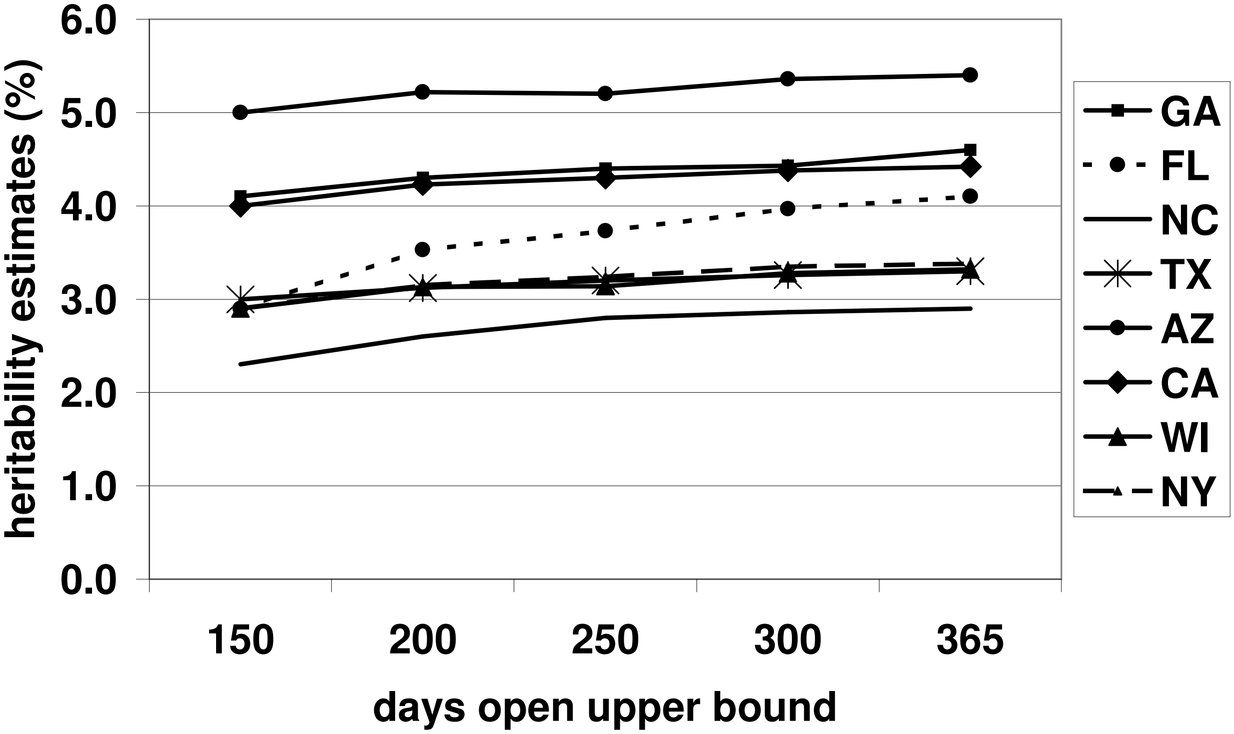

Figure 4.6. Heritability estimates for pregnancy rates across different days open upper bounds.

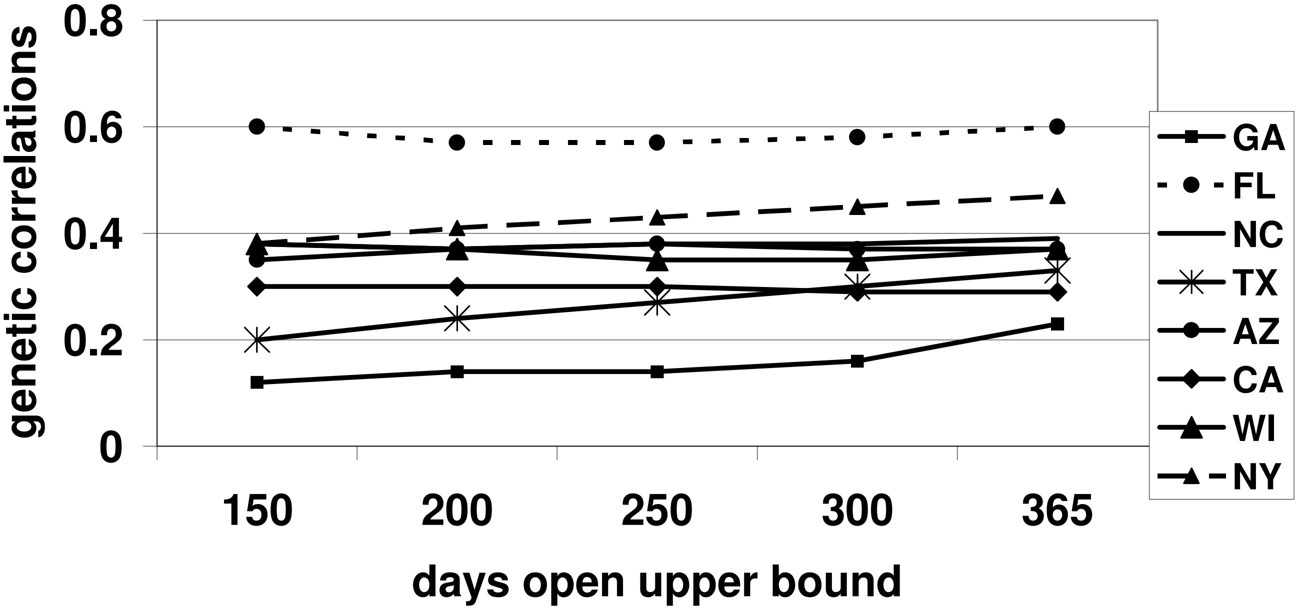

Figure 4.7. Estimates of genetic correlations between 305 –d milk yield and days open.

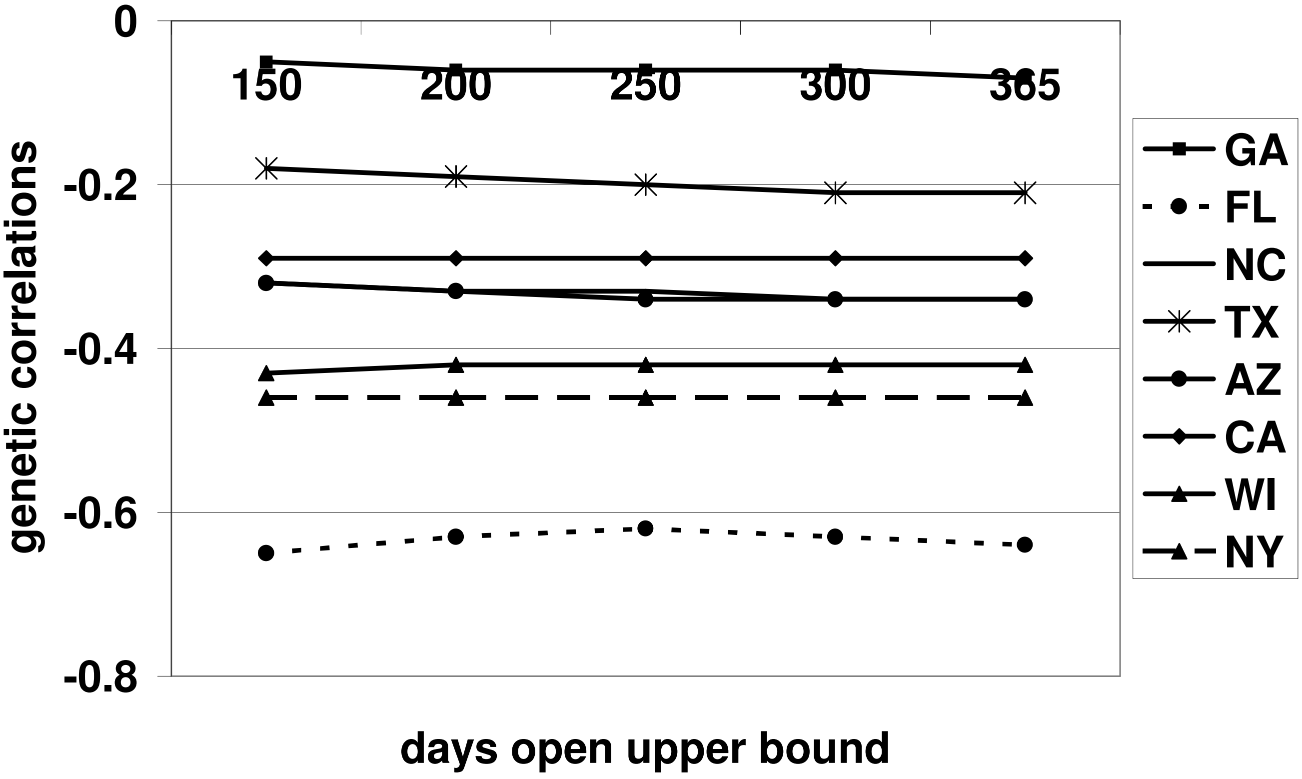

Figure 4.8. Estimates of genetic correlations between 305 –d milk yield and pregnancy rate across different days open upper limits.

CHAPTER 5

GENETIC COMPONENTS OF DAYS OPEN UNDER HEAT STRESS[1]

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[1] Oseni, S., I. Misztal, S. Tsuruta, and R. Rekaya. Submitted to the J. Dairy Science 04-13-04.

ABSTRACT

A reaction norm approach was used to estimate the genetic parameters of days open (DO) with a model that accounted for heat stress. Data included DO records for GA, TN and NC. A fixed effect model included herd-year, month of calving, age of cow, and a regression on 305-d milk yield. The reaction norm model additionally included the effect of animal with random regression on a heat stress index (HI), which was standardized solutions to months of calving derived from the fixed effect model; residual variance was assumed to be a function of the HI. The shape of the distribution of the HI was close to a sinusoidal function with the highest value in March/April and the lowest value in September. Genetic and residual variances and heritabilities were highest for spring calvings and lowest for fall calvings. The variance associated with the random regression of the highest level of HI was 33% of the genetic variance of the regular animal genetic effect. Genetic correlation between these effects was 0.67. As a validation, DO data were grouped into four seasons of calving and treated as different traits. A four-trait mixed linear model that included the above listed fixed effects except the month of calving was used to analyze the grouped data. In general, the estimates of genetic and residual variances of the multiple trait analyses followed those of the reaction norm model. Genetic correlations of spring with summer, and fall with winter were both 0.90. Genetic correlations between spring/summer and fall/winter were around 0.80. The reaction norm model for DO allows inexpensive but limited genetic evaluation of fertility under heat stress. Results of such an evaluation may strongly depend on editing criteria and model specifications.

Key words: Days open, Heat stress index, Month of calving, Reaction norm, Random regression model

Introduction

Current emphasis on fertility traits in dairy herds arises from the deterioration in fertility levels as well as the negative economic implication of this trend on the profitability of commercial dairy herds. Fertility traits, in general, have a very high environmental component and the season (or month) of calving, in addition to the herd effect, has been identified as a major source of variation for these traits (Badinga et al., 1985; Cavestany et al., 1985; Faust et al., 1988; Ray et al., 1992; Eicker et al., 1996). Seasonal trends for fertility traits are well known. Several investigators (Thatcher et al. 1978; Seykora and McDaniel, 1983; Silva et al. 1992; Marti and Funk, 1994; VanRaden et al. 2002; Oseni et al, 2003) have reported that days open (DO) were longest for spring calvings and shortest for fall calvings in the USA. This trend was attributed to the depressed fertility during the summer time, when spring calvers are ready for re-breeding. High temperatures during the summer have been implicated for the reduced fertility in that season (Wolfenson et al., 2000). While the seasonal (phenotypic) trend for DO is well established, few studies have been done to estimate genetic parameters of DO across seasons of calving (Hahn, 1969; Seykora and McDaniel, 1983; Faust et al., 1989). These authors, using paternal half-sib analyses, reported that heritability estimates for DO and first service conception rate were higher for spring than for fall calvings, and concluded that genetic differences in fertility levels are best observed under sub-optimal (stressful) conditions.

The modeling of the genetic component of heat stress for non-return rate (NR) in Southeastern US was conducted by Ravagnolo and Misztal (2002). They estimated genetic parameters for NR using a model with a random regression on temperature-humidity index (THI). They reported that the variance of heat stress was zero at THI =70 but it was as large as the general additive variance at THI = 84 for NR at 90 d, indicating that genetic variation in heat tolerance exists for NR90 d at high levels of THI among Holsteins. The model for NR cannot be applied directly to DO because this trait is not directly associated with a particular date. The alternative is using an index based on month of calving (MOC), since such an index accounts for most of the fluctuations in DO across calving seasons. This is similar to the reaction norm model, since the stress index is implemented as solutions to MOC re-parameterized to a scale of 0 (no heat stress) to 1 (maximum heat stress). The reaction norm approach is useful when phenotypes change gradually and continuously over an environmental gradient and has been used successfully in the evaluation of animals for phenotypic plasticity (differences between phenotypes) across different environments (De Jong, 1995; De Jong and Bijma, 2002; Kolmodin et al. 2002). The objectives of this study are to analyze the genetic relationship between generic (no heat stress) and heat tolerance effects for DO and to examine changes in genetic parameters of DO by MOC using a reaction norm model.

Materials and Methods

Fertility data on first parity calvings of Holstein cows for three states (GA, NC, TN) were extracted from the AIPL/USDA database. These datasets spanned a period of six years (1997 to 2002). A summary of the datasets is shown in Table 1. In data editing, DO records less than 22 d were not included, while records greater than 22 d and less than 50 d were set to 50 d. An upper limit of 250 d was set; records of DO greater than 250 d were set to 250 d. Age classes were defined using 3 months intervals as follows: class 1: $\leq$ 23 months; class 2: 24 -26 months; class 3: 27-29 months of age; class 4: 30-32 months; class 5: 33 - 35 months and class 6: 36-38 months. Analyses were restricted to first parity records.

Three sets of analyses were conducted. The first analysis fit a fixed effects model to DO to generate solutions for months of calving effect. The model used was:

$\mathbf{y_{ijkl} = hy_i + moc_j + age_k + b(milk) + e_{ijkl}}$ **Model 1**

where y_{ijkl} = the observed DO for animal l in the herd-year (hy_i) class i (i=3073), calving in month j (j=1,12), belonging to the age-class k (k=1,6); b(milk) = fixed regression on 305-d milk yield; and e_{ijkl} = random error associated with each observation.

Heat stress index (HI) was computed as the standardized solutions for months of calving derived from Model 1 using the following formula:

$\mathbf{HI = (sol_j - sol_{min})/ (sol_{max} - sol_{min})}$ where sol_j is the least squares solution for the MOC j (j=1,12); sol_{min} and sol_{max} are the minimum and maximum solutions for MOC respectively.

Seasonality of calving (SOC) was defined as follows:

SOC = (number of calvings in the jth MOC)/(number of calvings in the MOC with the maximum calvings).

The second analysis fit an animal model augmented by a random regression on **HI** as follows:

$\mathbf{y_{ijklmn} = hy_i + moc_j + age_k + b(milk) + a_{0l} + a_{11}h_m + e_{ijklmn}}$ **Model 2**

where y_{ijklmn} = observed DO for animal l in the herd-year class i, calving in the month j, belonging to the age-class k and level m of the HI; hy_i ,moc_j , age_k and b(milk) are as defined in Model 1; a_{0l} represents the additive regular merit of cow l (l=1,68,720); h_m is the HI function ($0 \leq m \leq 1$) and represents the explanatory variable in the reaction norm model; a_{1l} can be interpreted as the additive linear effect of heat tolerance of cow l and e_{ijklmn} = the random error associated with each observation. For this model, residual variances were treated as heterogeneous, using the 'heterogeneous residual variance option" of the AIREMLF90 package (Misztal et al., 2002) as modified by Tsuruta et al., (2003).

The (co)variance structure for Model 2 is:

$$\text{var}\begin{bmatrix} a \\ h \end{bmatrix} = \begin{bmatrix} A\sigma_a^2 & A\sigma_{ah} \\ A\sigma_{ah} & A\sigma_h^2 \end{bmatrix}; \text{var}(e) = R = diag\{I_{n1}\sigma_{e1}^2, I_{n2}\sigma_{e2}^2, \ldots\ldots\ldots, I_{n12}\sigma_{12}^2\}$$

where A is the genetic relationship matrix among animals; σ^2_a, σ^2_h and $\sigma_{a,h}$ represent the additive genetic variances for the generic (no heat stress) and heat tolerance effects for DO and their covariance respectively; R is a diagonal matrix of heterogeneous residual effects partitioned for each MOC; $I_{n1}\sigma^2_{e1}$, $I_{n2}\sigma^2_{e2}$, …..,$I_{n12}\sigma^2_{e12}$ represent the identity matrices for the residual variances for each MOC with appropriate dimensions and n = number of records for each MOC. The heat tolerance effect determines the relative change in the fertility status of the cow for each unit increase in the HI function (Ravagnolo and Misztal, 2002).

A third analysis used data sub-sets based on seasons of calving as follows: winter (December to February); spring (March to May); summer (June to August) and fall (September to November). A 4-trait model based on seasons was fit as follows:

$$\mathbf{y_{ijklt} = hy_{it} + age_{jt} + b(milk) + a_{kt} + e_{ijklt}} \qquad \textbf{Model 3}$$

where $\mathbf{y_{ijklt}}$ = observed DO on cow l for trait t (t =1,4 for winter, spring, summer and fall respectively) in the herd-year class i in the age-class j; all other effects are as previously defined. For all the models, (co)variance components were estimated using the Average Information REML procedures via AIREMLF90 (Misztal et al., 2002).

Results and Discussion

Table 2 shows the distribution of records, means, standard deviations, and the HI function of DO for each MOC. The plot of least squares means of DO is shown in Figure 1. Days open were longest for March/April (spring) calvings and lowest for September (fall) calvings, in agreement with reports in the literature (Gwazdauskas, 1985; Marti and Funk, 1994). Spring calvings are associated with prolonged DO for several reasons – intentional delay by the farmer due to reasons related to poor conception in the summer period when spring calvers are being re-bred (Badinga et al., 1985; Cavestany et al., 1985; Eicker et al., 1996), use of less expensive semen during the summer and prolonged VWP on account of high milk yield (Luna-Dominguez et al., 2000; Arbel et al. 2001). Differences between seasons are also shown by the distribution of records across calving seasons (Figure 2). For fall, winter and summer calving DO records, highest frequencies were at 70 d, 80 d and 100 d post-calving, respectively. Further, the rate of decline differs for these three seasons. It was steep for winter calvings, slow for summer while fall records were intermediate between these seasons. In sharp contrast, spring calving records had double peaks at 65 d and 215 d, corresponding to the peaks for cows pregnant pre - and post-summer, respectively. Oseni et al. (2003) have shown that spring MOCs have a bimodal distribution for DO due, perhaps, to prolonged VWP, intentional delay or poor fertility in the summer when both winter and spring calvers are being re-bred.

Figure 3 shows the least squares means of DO for each MOC as deviations from September calvings. The range of DO across all MOCs was 50 d, implying that, on average, cows calving in March remain open 50 d longer than those calving in September. The grouping of MOCs into seasons of calvings (Table 3) shows that spring calvings recorded longest DO, followed by winter calvings while summer and fall had shortest DO intervals. Marti and Funk (1994) reported similar findings. Results also indicate that, on the average, spring calvers were open for about 36 d longer than fall calvings. Ray et al. (1992) reported a range of 28 d for spring calvers in Arizona while Seykora and McDaniel (1983) reported that spring calvings were open 17 d longer than fall calvings in NC herds. Disparities in literature reports are to be expected since Washburn et al. (2002) have shown that mean DO changed drastically over time from 125 d in 1983 to 170 d in 1999 for states in the Southeastern USA.

The distribution of DO records by MOC (Table 2) and the SOC (Figure 4) also showed seasonal trends. The highest number of calvings occurred in September (corresponding to successful December/January or winter matings) while the lowest number of calvings was in May (corresponding to successful July/August or summer matings of the previous year. High temperature-humidity index in the summer in Southeastern USA may explain these disparities between seasons in the frequencies of calvings (Wolfenson et al. 2000).

The HI function is shown in Table 2 and Figure 5. This function has a range of 0 (no heat stress, or best MOC) to 1 (highest level of heat stress, worst MOC). This function was calculated using the least squares means of DO for each MOC and it represents the explanatory variable in the reaction norm model (Model 2). Despite the fact that some information in the dependent variable (DO) is included in the explanatory variable (HI), this model has been successfully applied in several studies on phenotypic plasticity across different environments (De Jong, 1995; De Jong and Bijma, 2002; Kolmodin et al., 2002). With respect to fertility, some advantages in this approach include the fact that calving seasons (or the environment) can be categorized as synergistic or antagonistic or nil in the expression of the trait.

Figures 6 - 8 show the residual and additive genetic variances and heritability estimates derived from the random regression model (Model 2) and the multiple trait model (Model 3). Both models showed seasonal fluctuations in all three parameters of interest. The Model 3 showed greater spread in variances and heritabilities. Highest genetic variance from the Model 2 was in March/April calvings and lowest estimates were for fall (September) calvings, while Model 3 estimates for genetic variance showed a steady decline from winter through spring, summer and with lowest estimates in the fall calving season. Variances in the random regression model (Model 2) are restricted by the shape of the HI function, although the restrictions could be lowered if the model was extended to e.g. second – order regressions. On the other hand, variances in the multiple trait model (Model 3) cannot change within traits. This model has many more parameters resulting in larger sampling variances. The genetic correlations between the regular and heat stress effects from Model 2 was 0.67 while the correlations between seasons were about 0.80 (Table 6). These correlations indicate that animals rank mainly identically during all the calving seasons. This contradicts the results of Ravagnolo and Misztal (2002) for NR90 where the correlations were negative. In an unpublished study, we used the same model for pregnancy rate, a trait that places higher emphasis on lower DO. In that study, the correlations were negative. One possibility is that the analyses with DO were influenced by management interventions that resulted in large DO. Such interventions could be intentional delay in breeding especially for high producing cows or different applications of estrus synchronizations/ovulations protocols during different seasons.

Seasonal difference in genetic variations for DO is shown from the results of both models. This is further validated by the estimates for heritability (Figure 8). Both models show some approximations for heritability estimates across seasons. Heritability estimates were highest for spring calvings (6%) and lowest for fall (2 - 3%). These estimates indicate that the seasonal fluctuations in DO have some genetic component, with implications that sires can be selected for lower seasonal DO. These results agree with previous studies (Seykora and McDaniel, 1983; Faust et al., 1989). Seykora and McDaniel (1983) reported heritability estimates of 9% and 5% for spring and fall calvings respectively, supporting the argument that environmental stress enhances the expression of genetic variability. A Similar conclusion was drawn by Faust et al., (1989) who reported that heritability estimates from paternal half-sib analysis for first service conception rate for warm season were two times higher than estimates from cooler seasons. These authors also noted that sires re-ranked more often than predicted by inheritance and suggested a sire by season interaction for first service conception rate.

The usefulness of DO for heat stress studies is limited without additional/ comprehensive information on precise mating dates, length of the VWP, persistency of mating, preferential husbandry and reproductive protocols (e.g. estrous synchronization, timed AI, etc). Prolonged DO under heat stress could have occurred for many reasons and these were neither available nor accounted for in this study. Thus, highly productive cows may have artificially low evaluations under heat stress.

Conclusions

The reaction norm model allows inexpensive genetic evaluation for DO under heat stress since it neither requires the collection and analysis of weather information nor detailed fertility data. However, its usefulness is in large part, conditioned by the availability and quality of the recorded fertility data. Results showed that seasonal fluctuations in DO have a genetic component and that selection of sires for lower seasonal DO may be a possibility.

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Table 5.1: Number of herds, records, means and standard deviations of days open by state

State	Records	Herds	Mean	SD
GA	21,461	206	154	72
NC	28,217	262	151	71
TN	19,042	274	152	71
All	68,720	742	152	72

Table 5.2. Distribution, least squares means, standard deviations and heat stress index function (HI) of days open across months of calving (MOC)

MOC	**Records**	**Means**	**SD**	**HI***
January	6,488	151	77	0.62
February	5,239	159	78	0.80
March	6,189	168	75	1.00
April	5,054	167	68	0.99
May	4,540	164	64	0.92
June	4,638	151	64	0.62
July	5,092	136	64	0.28
August	6,469	129	67	0.11
September	7,461	124	68	0.00
October	5,928	130	70	0.13
November	5,810	135	71	0.26
December	5,812	140	74	0.37
All MOCs	68,720	152	72	0.51

*HI are standardized solutions of days open for each month of calving

Table 5.3. Records, least squares means, standard deviations and mean deviations* of days open across calving seasons

Season	**Records**	**Means**	**SD**	**Deviations from Fall ***
Winter	17,539	150	77	20
Spring	15,783	166	70	36
Summer	16,199	139	65	9
Fall	19,199	130	70	0
All	68,720	152	72	22

* Fall calvings used as a baseline

Table 5.4. Estimates of additive genetic (g) and residual (r) variances and heritabilities (h^2) based on the random regression model (Model 2) across months of calvings (MOC).

MOC	**g**	**r**	**h^2(%)**
January	196	4240	4.4
February	223	4311	4.9
March	255	4389	5.5
April	254	4386	5.5
May	241	4356	5.2
June	195	4238	4.4
July	152	4112	3.6
August	133	4047	3.2
September	123	4008	3.0
October	135	4054	3.2
November	150	4104	3.5
December	162	4144	3.8
All MOCs	185	4199	4.2

Table 5.5. Additive genetic (g) and residual (r) variances and heritability estimates for days open across seasons of calvings (Model 3)

Seasons	r	g	h^2(%)
Winter	5028	244	4.6
Spring	3788	227	5.7
Summer	3343	113	3.3
Fall	4082	80	1.9

Table 5.6. Genetic correlations between days open in different seasons

Seasons	Winter	Spring	Summer	Fall
Winter	1.00	0.84	0.82	0.90
Spring		1.00	0.90	0.83
Summer			1.00	0.78
Fall				1.00

Seasons were defined as follows:

Winter = December – February calvings

Spring = March – May

Summer = June – August

Fall = September - November

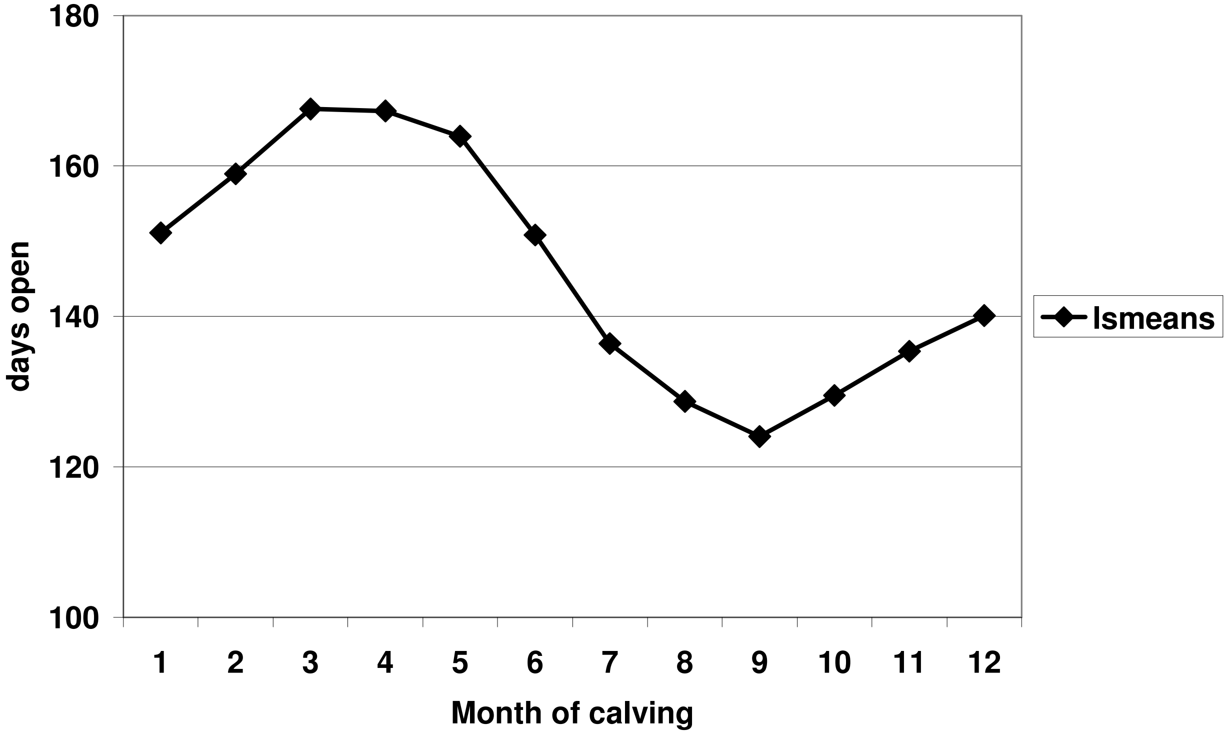

Figure 5.1. Least squares means of days open across months of calving (combined data from GA, TN, NC)

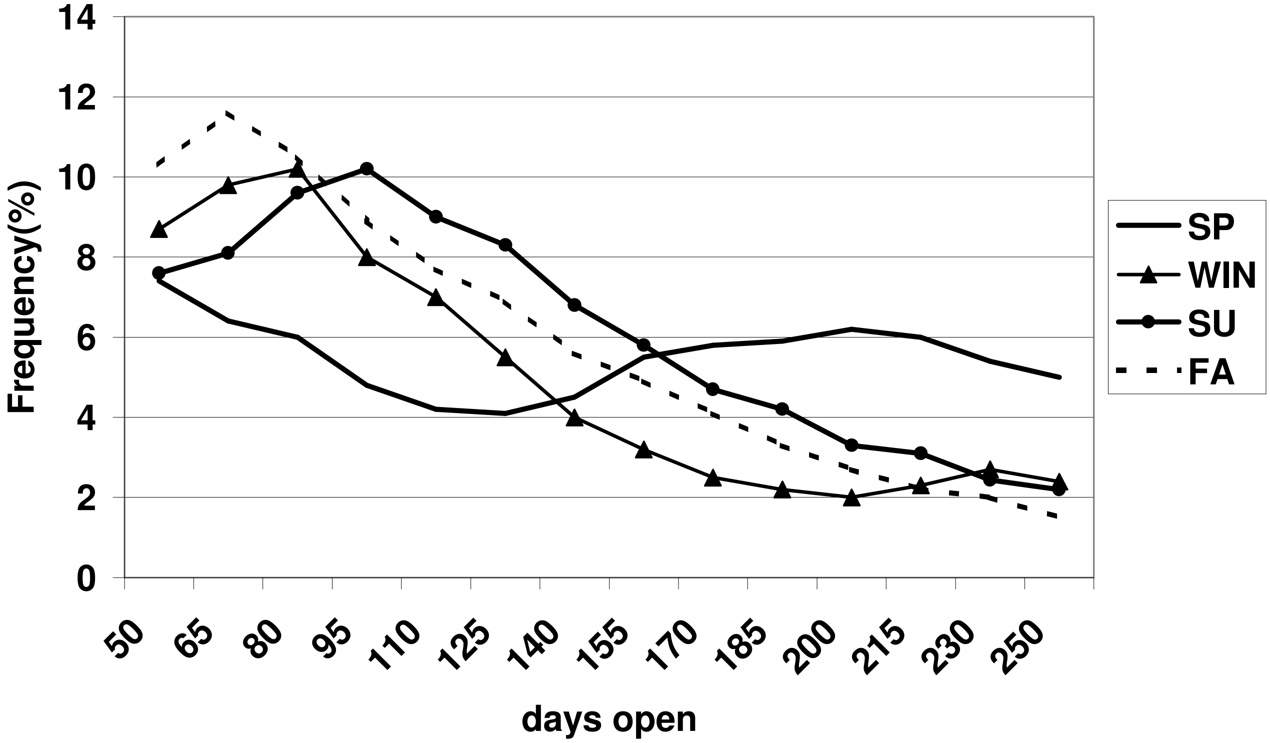

Figure 5.2. Frequency distribution for days open *up to* 250 d post-calving, by season of calving (SP = spring; WIN = winter; SU = summer, and FA = fall calvings).

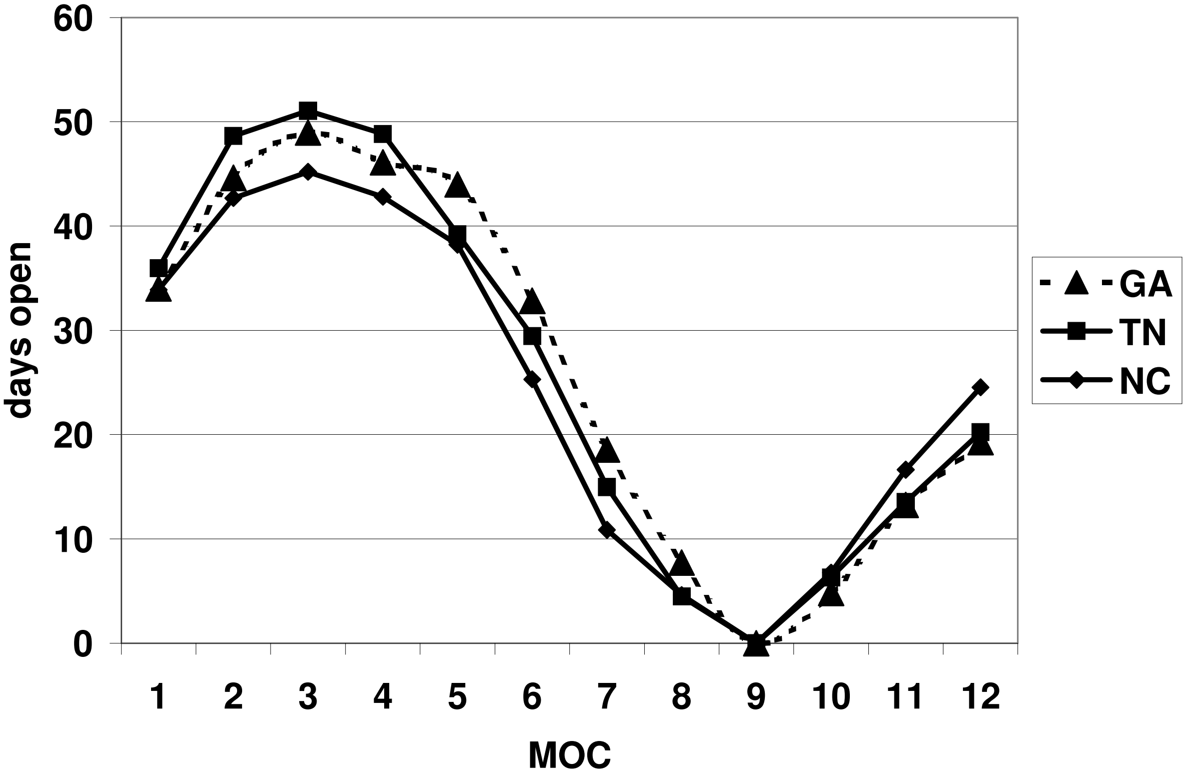

Figure 5.3. Least squares means for days open as deviations from September calving means for GA, TN, NC.

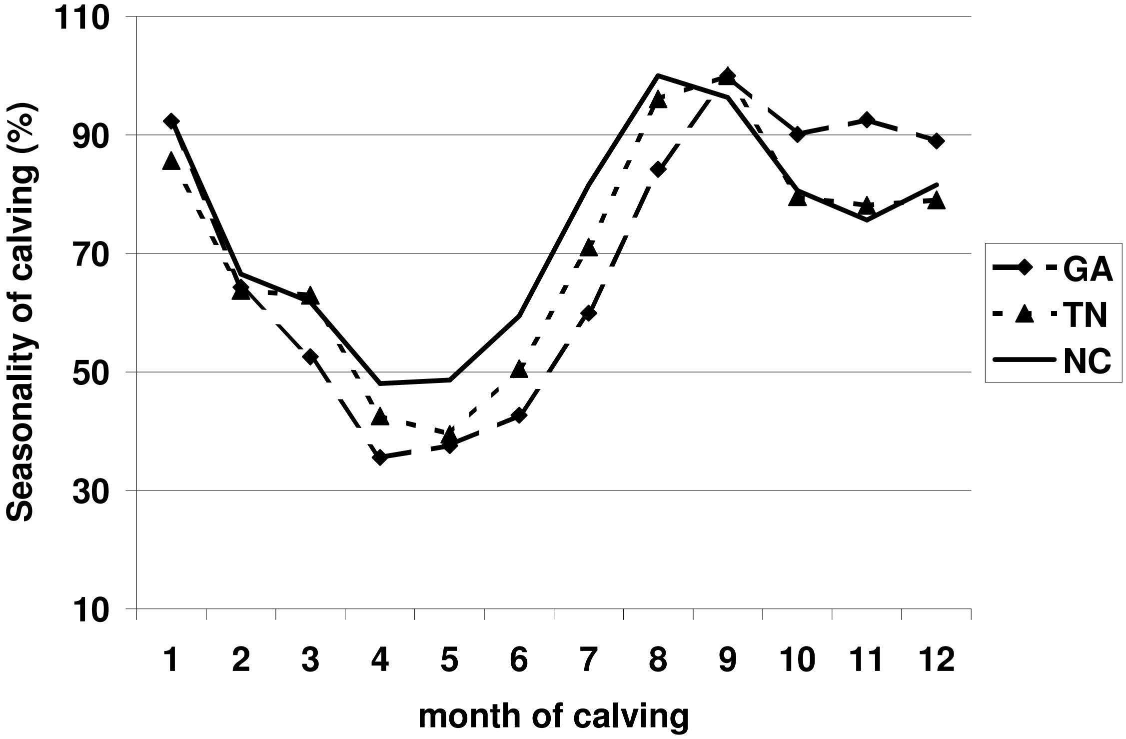

Figure 5.4. Seasonality of calving for GA, TN and NC.

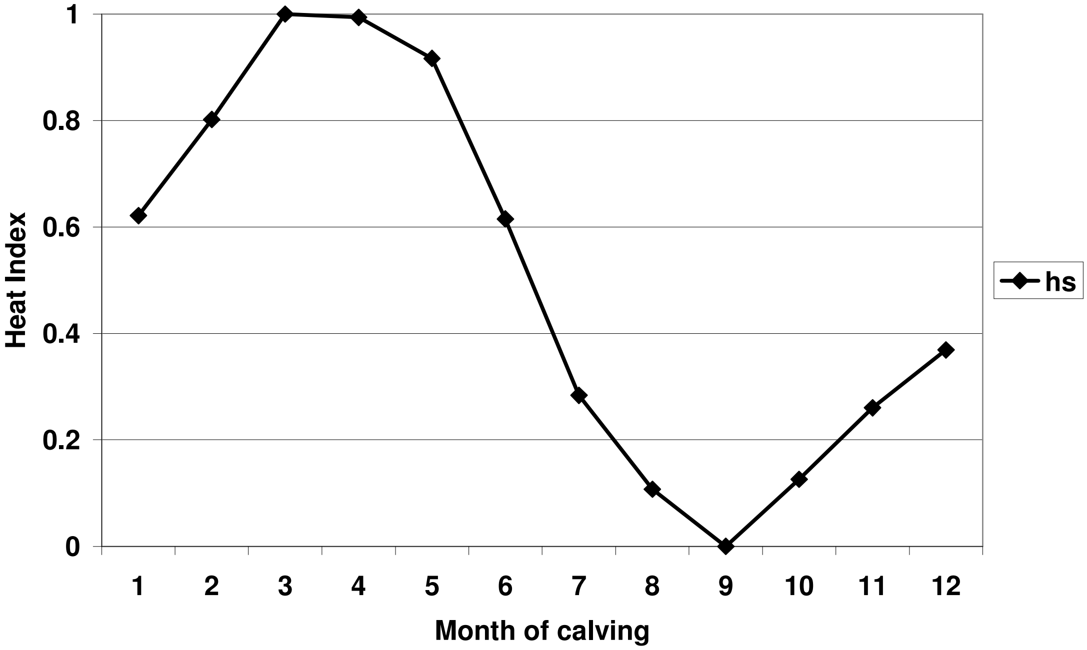

Figure 5.5. Heat stress index based on the least squares means for days open across months of calving (combined datasets for GA, TN, NC).

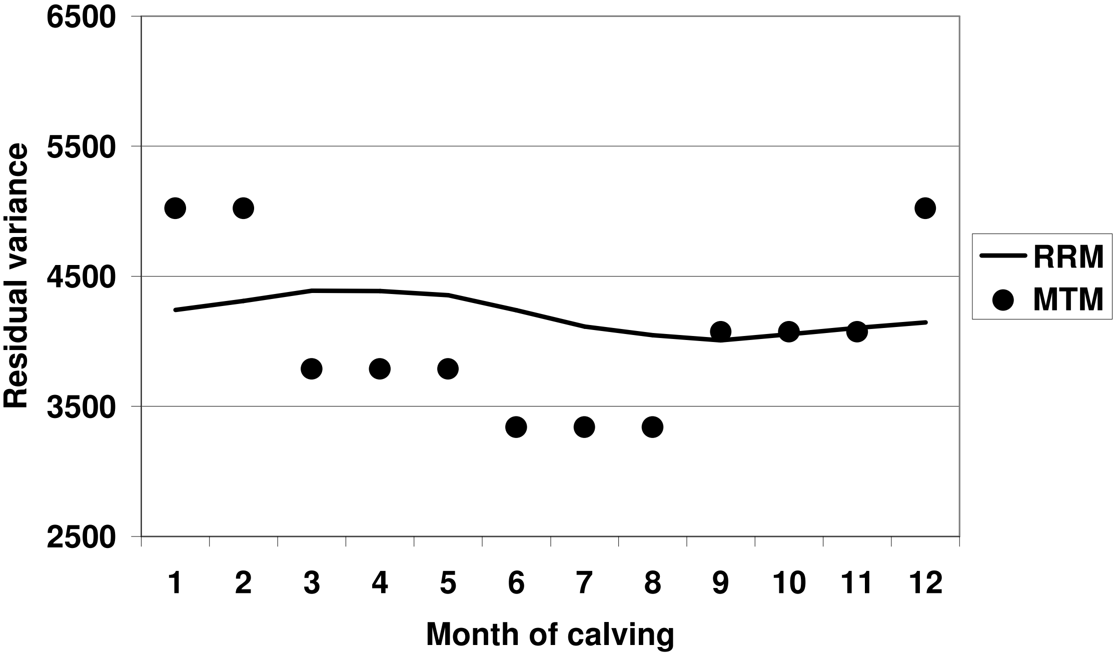

Figure 5.6. Estimated residual variances from random regression (RRM, Model 2) and the multiple trait models (MTM, Model 3) across calving seasons (combined datasets for GA, TN, NC).

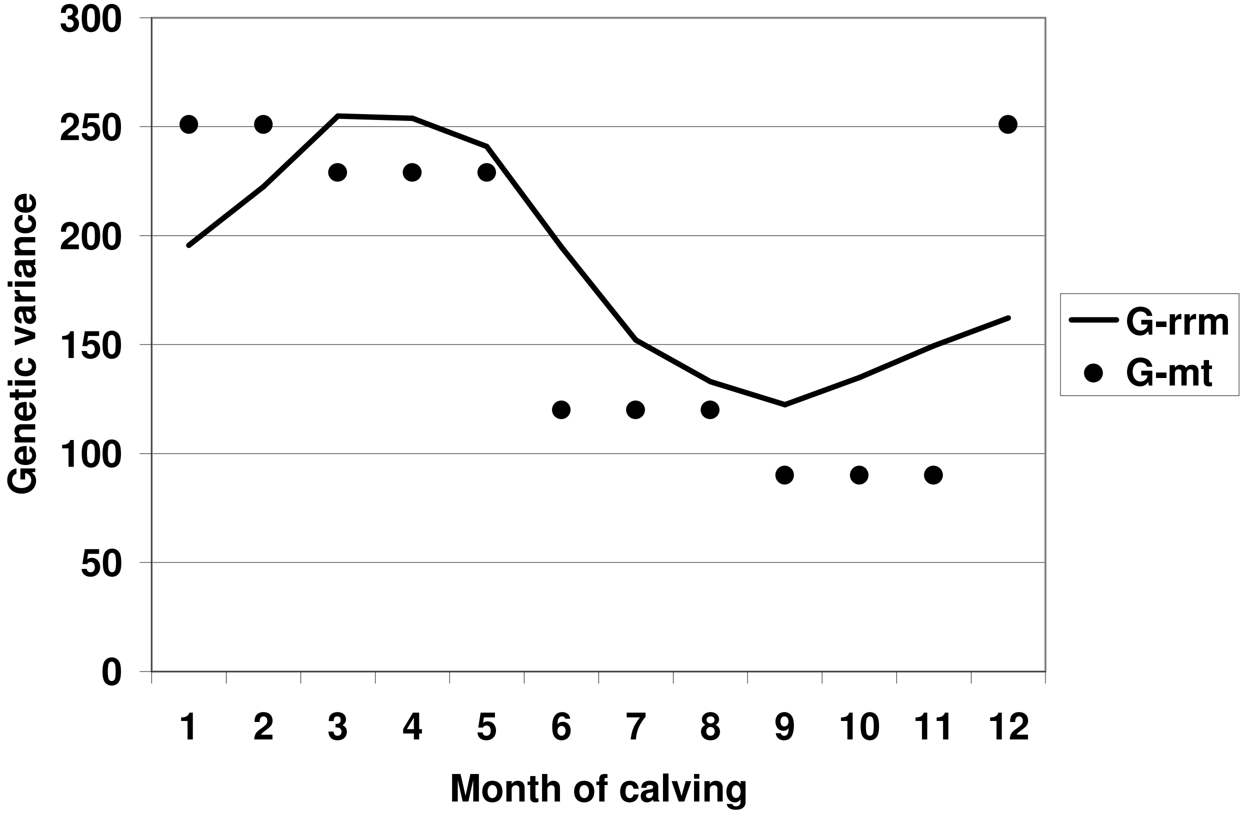

Figure 5.7. Estimated additive genetic variances (G) from Model 2 (G-rrm) and Model 3 G-mt) across calving seasons (combined datasets for GA, TN, NC).

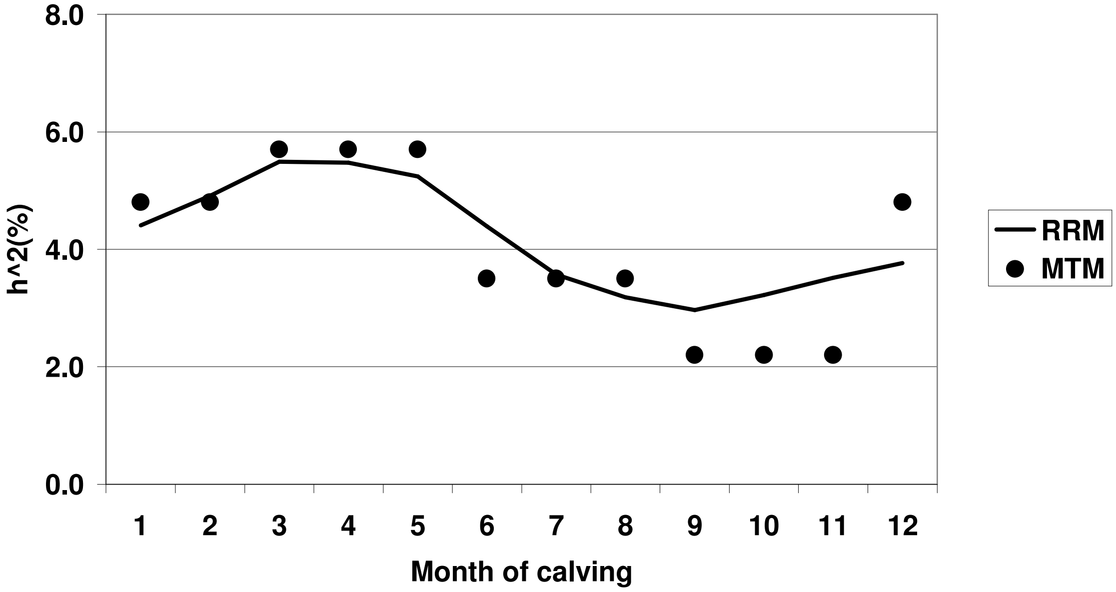

Figure 5.8. Heritability estimates from random regression (RRM, Model 2) and multiple trait (MTM, Model 3) models across calving seasons (combined datasets for GA, TN, NC).

CHAPTER 6

ADDITIONAL ANLYSES

The reaction norm and the multiple trait models for days open (DO) in the previous chapter were applied to pregnancy rate (PR). The objective was to examine the pattern of changes of PR across calving months and to compare these fluctuations with the trends observed for DO. Results from the multiple trait and the random regression models for PR showed close agreement. These results revealed that seasonal trends for all parameter estimates for PR are comparable to the patterns observed for DO in chapter 5.

Charts for the distribution of PR by calving seasons (figure 6.1), monthly heat index (figure 6.2), mean PR by month of calving (figure 6.3), heritabilities (figure 6.4), residual (figure 6.5) and additive genetic variances (figure 6.6) across months of calving are attached. These results are presented without discussion, with the hope that they might be useful in future studies, when more knowledge is accumulated about the interaction of PR and DO with seasonal heat stress.

Table 6.1. Distribution, least squares means (Means), standard deviations and heat stress index function (HI) for pregnancy rate across months of calving (MOC)

MOC	**Records**	**Mean (PR)**	**HI (PR)**
January	6,488	29	.44
February	5,239	28	.50
March	6,189	26	.71
April	5,054	24	.82
May	4,540	22	1.0
June	4,638	25	.79
July	5,092	28	.50
August	6,469	32	.20
September	7,461	34	0.0
October	5,928	31	.21
November	5,810	29	.41
December	5,812	29	.45
All MOCs	68,720	28	.50

Table 6.2. Records, least squares means (Means), standard deviations and mean deviations* of pregnancy rate across calving seasons

Season	**Records**	**Mean_PR**	**SD**	**Deviations from Spring***
Winter	17,539	29	24	5
Spring	15,783	24	23	0
Summer	16,199	29	23	5
Fall	19,199	32	23	8
All	68,720	29	23	5

Table 6.3. Estimates of additive genetic (g) and residual (r) variances and heritabilities (h^2) for pregnancy rate, based on the random regression model (Model 2) across months of calvings (MOC).

MOC	**g**	**r**	**h^2**
January	14	470	2.78
February	14	465	2.84
March	14	443	3.09
April	14	432	3.22
May	15	415	3.45
June	14	435	3.18
July	14	465	3.84
August	13	497	2.53
September	13	519	2.34
October	13	495	2.55
November	13	474	2.75
December	14	470	2.78
All MOCs	14	465	2.86

Table 6.4. Additive genetic (Va) and residual (Ve) variances and heritability estimates for pregnancy rate across seasons of calvings from the multiple trait model.

Seasons	**Ve**	**Va**	**h^2(%)**
Winter	514	16	2.9
Spring	436	20	4.4
Summer	392	10	2.4
Fall	483	10	2.1

Table 6.5. Genetic correlations between pregnancy rates in different seasons

Seasons	**Winter**	**Spring**	**Summer**	**Fall**
Winter	1.00	0.86	0.95	0.98
Spring		1.00	0.96	0.81
Summer			1.00	0.89
Fall				1.00

Seasons were defined as follows:
Winter = December – February calvings
Spring = March – May
Summer = June – August
Fall = September – November

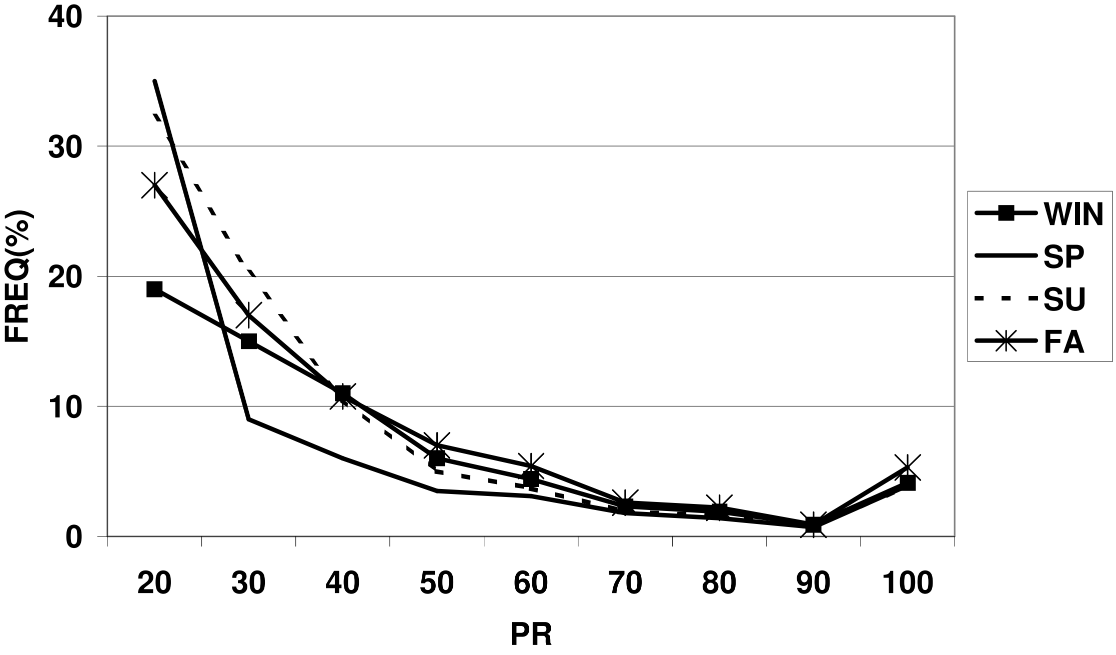

Figure 6.1. Frequency distribution of pregnancy rates up to 250 d post-calving, by season of calving (SP = spring; WIN = winter; SU = summer and FA = fall calvings).

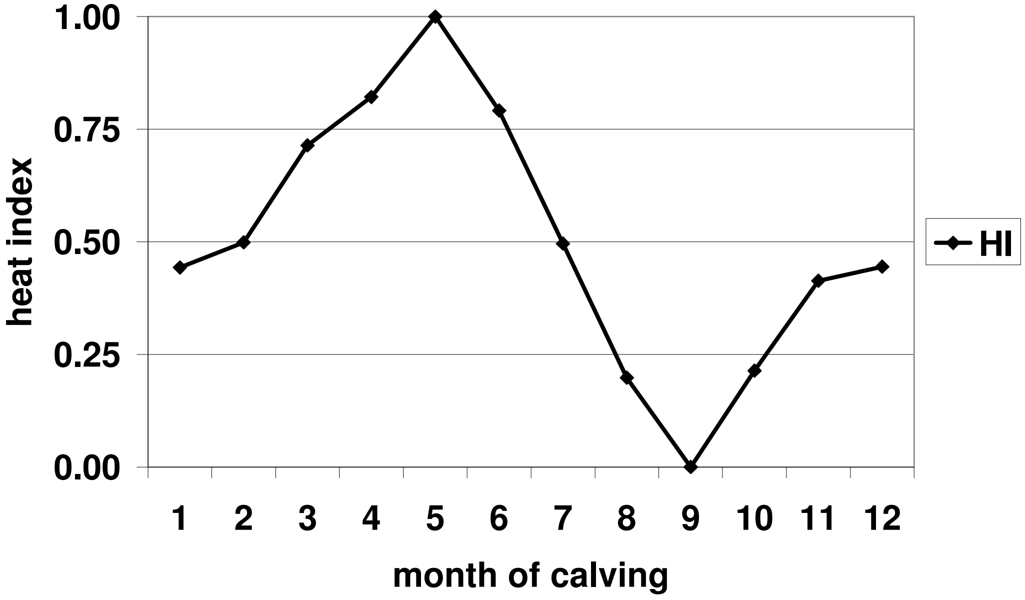

Figure 6.2. Heat stress index (HI) based on the least squares means for pregnancy rates across months of calving (combined datasets for GA, TN, NC).

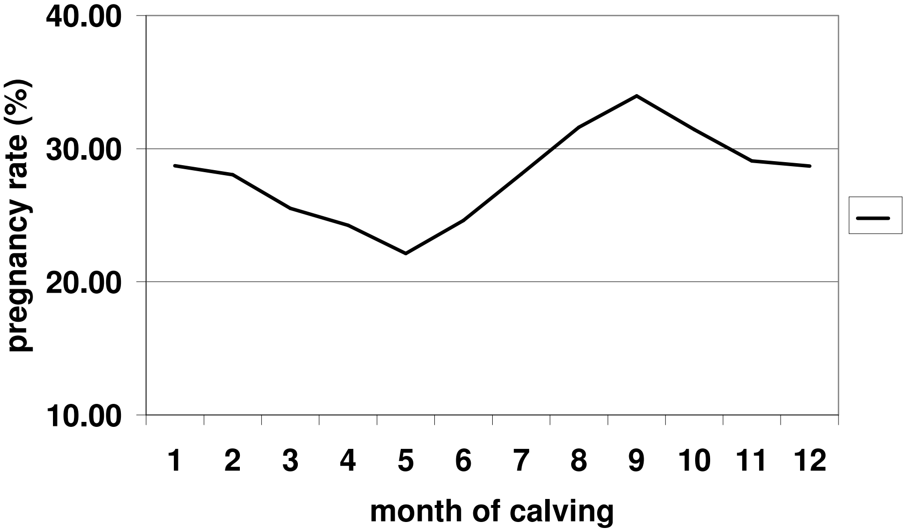

Figure 6.3. Least squares means for pregnancy rates for the combined data sets for GA, TN, and NC.

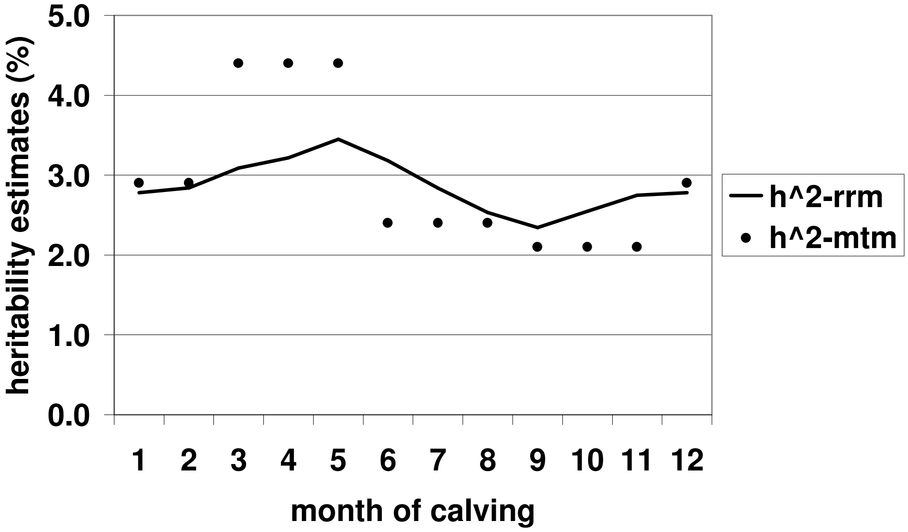

Figure 6.4. Heritability estimates for pregnancy rate from the random regression (h^2-rrm) and multiple trait (h^2-mtm) models across calving seasons (combined datasets for GA, TN, NC).

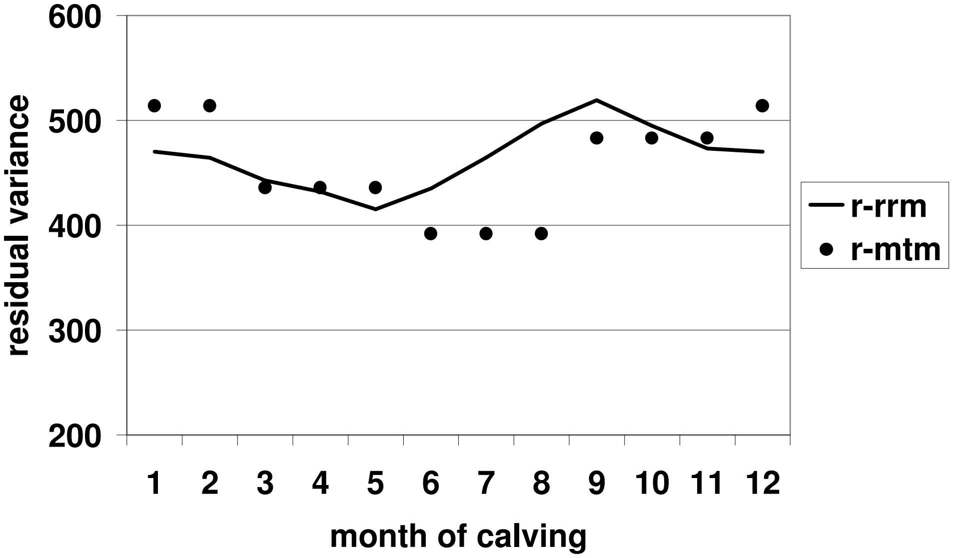

Figure 6.5. Estimates of residual variances from the random regression (r-rrm) and multiple trait (r-mtm) models across calving seasons (combined datasets for GA, TN, NC).

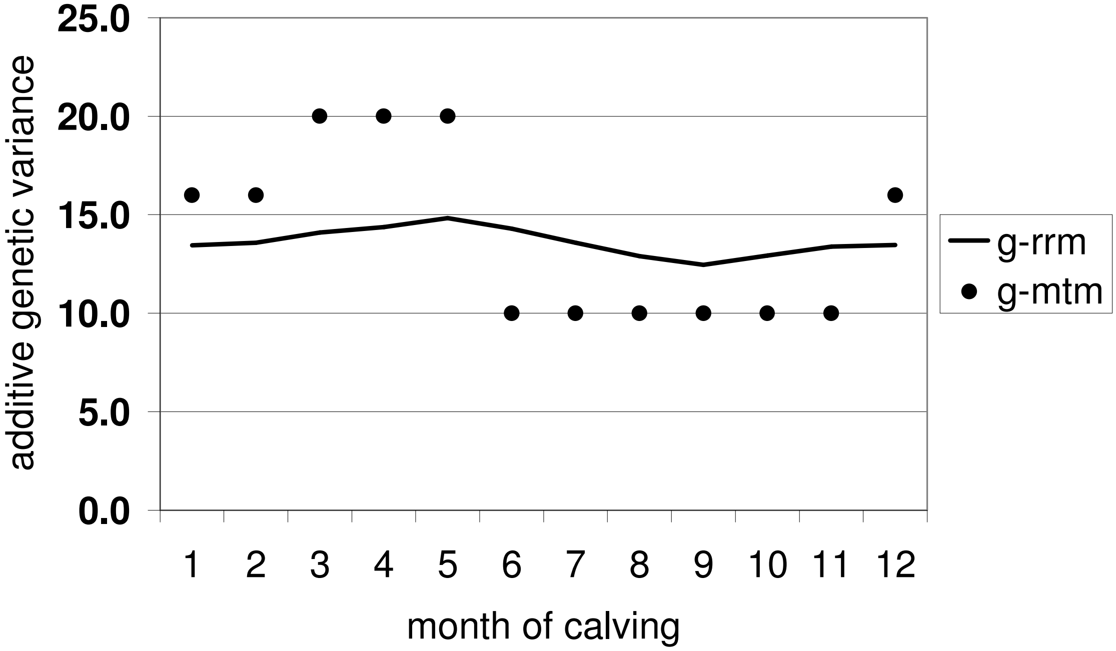

Figure 6.6. Estimates of genetic variances for pregnancy rate from the random regression (g-rrm) and the multiple trait models (g-mtm) across calving seasons (combined datasets for GA, TN, NC).

CHAPTER 7

CONCLUSIONS

Days open is a complex trait that is influenced by regional and seasonal factors. Heat stress in the form of seasonal breeding and high variations of days open is mostly present in the Southeast, parts of the Southwest and Midwest. Long days open records do not necessarily reflect poor fertility, since they could also be result of sound management decisions. It is recommended that potential genetic evaluations for days open as a fertility trait should consider those decisions, e.g., by including additional information or by a sophisticated statistical model.

The study on the effect of editing criteria on the genetic parameters for days open and pregnancy rate showed that the upper limits on DO affected states differently, reflecting the large influence of environmental and management practices on the estimates of genetic parameters across states. Estimates of variance components are more stable for PR than for DO. Differences between states in genetic parameters for PR depend strongly on the assumed length of the VWP. Genetic variations in DO upper bounds > 250 d is minimal and records of DO can be limited to 250 d. Genetic correlations between DO (or PR) and 305 –d milk yield are antagonistic, with genetic correlations strongly dependent on the state. Days open and PR can be analyzed more accurately when information on management of fertility such as length of the VWP, service period, estrous synchronization, and bST are available.

Reaction norm model allows inexpensive genetic evaluation for days open under heat stress since it does not require the collection and analysis of weather information to quantify heat stress. However, its usefulness is in large part, conditioned by the availability and quality of the recorded fertility data. Results of this study showed that seasonal fluctuations in DO have a genetic component and selection of sires for lower seasonal DO may be a possibility.