

The role of energy balance in productivity, health, and fertility of first  
lactation Holsteins, Jerseys, and their reciprocal crosses

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## ABSTRACT

The Virginia Tech crossbreeding program began in the fall of 2002 by mating Holstein and Jersey foundation females to Holstein and Jersey bulls to create HH, HJ, JH, and JJ breed groups (sire breed listed first). Collection of daily dry matter intakes (DMI) began in the fall of 2005 and continued through spring of 2008. DMI were measured for two weeks out of every six week period in first lactation on 44, 32, 29, and 13 HH, HJ, JH, and JJ cows. Daily milk and body weights and monthly milk components were collected. The National Research Council (NRC) DMI prediction equation was used across breed groups to investigate breed differences. DMI prediction equations were developed across breeds. Random regression model were used to predict energy consumed (TEC), energy needed for production, maintenance, and growth at every week of lactation (WOL). Energy balance (EB) was calculated at every WOL by subtracting energy for production, maintenance, growth, and pregnancy from TEC. Common health events were recorded if they occurred in the first 100 days of lactation. Logistic regression was used to analyze health disorder. The HJ and JH were not different from each other in any analyses. The NRC under-predicted DMI for HH and over-predicted DMI for HJ, JH, and JJ. There were significant breed differences in the prediction equations developed. Results indicated that breeds differ in DMI after accounting for production and body weights. The HH cows consumed more energy than HJ and JJ cows. The HH, HJ, and JJ were not different from each other for production but were different from JJ. The JH allocated less energy to maintenance than the HH. There were no breed differences for weeks required to reach positive EB, return to positive cumulative EB, or EB at week 21 of lactation. The HJ, JH, and JJ were more likely to have an incidence of mastitis than HH. The HJ and JH were less likely to have an incidence of metritis than HH. The results indicate breeds

differ in DMI, and health diseases and evidence suggests differences in characterization of EB and warrants further investigation.

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## TABLE OF CONTENTS

<b>TITLE</b> .....	<b>i</b>
<b>ABSTRACT</b> .....	<b>ii</b>
<b>ACKNOWLEDGEMENTS</b> .....	<b>iv</b>
<b>CHAPTER 1</b> .....	<b>1</b>
<b>General Introduction</b> .....	<b>1</b>
1.1 INTRODUCTION .....	1
1.2 REFERENCES .....	3
<b>CHAPTER 2</b> .....	<b>5</b>
<b>Literature Review</b> .....	<b>5</b>
2.1 CROSSBREEDING.....	5
2.2 FEED EFFICIENCY AND ENERGY BALANCE.....	8
2.3 FEED INTAKES .....	12
2.4 ANALYSIS OF LONGITUDINAL DATA .....	14
2.4.1 Multivariate Approach .....	15
2.4.2 Random Regression Approach .....	16
2.5 REFERENCES .....	21
<b>CHAPTER 3</b> .....	<b>31</b>
<b>A Description of the Data</b> .....	<b>31</b>
3.1 ANIMALS .....	31

3.2 FEED INTAKES .....	32
3.2.1 Collection of Feed Intakes .....	32
3.2.2 Editing of Feed Intakes .....	33
3.3 MILK PRODUCTION .....	34
3.4 BODY WEIGHTS, HIP HEIGHTS, AND BODY CONDITION SCORES .....	35
3.5 REFERENCES .....	36
<b>CHAPTER 4 .....</b>	<b>42</b>
<b>Dry matter intake prediction equations for Holstein, Jersey, and reciprocal crosses in first lactation.....</b>	<b>42</b>
4.1 ABSTRACT.....	42
4.2 INTRODUCTION .....	43
4.3 MATERIALS AND METHODS.....	44
4.3.1 Experimental Design.....	44
4.3.2 Data .....	44
4.3.3 Data Edits.....	46
4.3.4 Comparison of Breeds for NRC (2001) Model.....	46
4.3.5 Prediction Equations .....	47
4.4 RESULTS AND DISCUSSION.....	48
4.4.1 The NRC Model.....	48
4.4.2 The Prediction Equations .....	49
4.5 CONCLUSIONS .....	52
4.6 REFERENCES .....	53
<b>CHAPTER 5 .....</b>	<b>72</b>

**Energy Balance in First Lactation Holsteins, Jerseys, and Reciprocal Crosses Estimated Using Random Regression..... 72**

5.1 ABSTRACT..... 72

5.2 INTRODUCTION ..... 73

5.3 MATERIALS AND METHODS..... 74

    5.3.1 Experimental Design..... 74

    5.3.2 Data ..... 75

    5.3.4 Calculations of Energy Balance..... 77

5.4 RESULTS AND DISCUSSION..... 79

    5.4.1 Components of Energy Balance..... 79

    5.4.2 Energy Allocation ..... 81

    5.4.3 Energy Balance ..... 82

5.5 CONCLUSIONS ..... 85

5.6 REFERENCES ..... 86

5.7 APPENDIX A..... 98

**CHAPTER 6..... 100**

**Energy balance and relationship to health and fertility in first lactation Holsteins, Jerseys, and reciprocal crosses ..... 100**

6.1 ABSTRACT..... 100

6.2 INTRODUCTION ..... 101

6.3 MATERIALS AND METHODS..... 102

    6.3.1 Data ..... 102

    6.3.2 Statistical Analyses ..... 103

6.4 RESULTS AND DISCUSSION..... 104



6.4.1 Health and Fertility Events .....	104
6.4.2 Health and Pregnancy Influence on Energy Balance and Intake .....	106
6.5 CONCLUSIONS .....	106
6.6 REFERENCES .....	108
<b>CHAPTER 7 .....</b>	<b>116</b>
<b>General Conclusions .....</b>	<b>116</b>

## LIST OF TABLES

Table 3.1. Rank for Net Merit (NM \$) within breed for Holstein and Jersey foundation sires in the Virginia Tech crossbreeding project.....	37
Table 3.2. Numbers of project cows by each sire within each breed group .....	38
Table 3.3. Coefficients for proportion of additive Holstein genes, maternal Holstein genes, and heterosis in breed groups.....	39
Table 3.4. Daily feed intake observations by breed group .....	40
Table 4.1. Description of potential variables (O = observed, C = calculated) to predict dry matter intake of first lactation Holstein, Jerseys, and reciprocal crosses.....	56
Table 4.2. Means and ranges by breed group for prospective variables in dry matter intake prediction equations .....	57
Table 4.3. Coefficients for additive Holstein genes, maternal Holstein genes, and heterosis in breed groups. ....	59
Table 4.4. Predicted and observed means, mean square prediction errors, root mean square prediction errors, and mean bias for predictions of dry matter intakes of first lactation animals from Holstein, Jersey, and reciprocal crosses using the NRC (2001) model (equation 3 in the text).....	60
Table 4.5. Prediction of residuals of DMI (kg/d) from FCM <sup>1</sup> , MBW <sup>2</sup> , and WOL <sup>3</sup> to the using the NRC (2001) model in Holstein, Jersey, and reciprocal crosses .....	61
Table 4.6. Pearson correlation coefficients among potential variables to predict DMI of Holsteins, Jerseys and reciprocal crosses.....	62
Table 4.7. Regression coefficients for all breed group models for Holstein, Jersey, and reciprocal crosses .....	64
Table 4.8. Regression coefficients for individual breed group models in first lactation Holstein, Jersey, and reciprocal crosses.....	65
Table 5.1. Daily means for HH, HJ, JH, and JJ for milk production, milk components, body weight, days pregnant, DMI, and NE <sub>L</sub> required for milk production .....	90
Table 5.2. Assumptions of mature body weight and calf birth weight made for HH, HJ, JH, and JJ for NE <sub>L</sub> (Mcal) energy calculations for pregnancy and growth from the NRC (2001).....	92

Table 5.3. Cumulative predicted $NE_L$ consumed, and $NE_L$ (Mcal) required for growth, maintenance, pregnancy, and production for Holstein, Jerseys, and reciprocal crosses over week 3 to week 43 of the first lactation .....	93
Table 5.4. Least square means for predicted percent of energy consumed used for growth, maintenance, pregnancy, and production for Holsteins, Jerseys, and reciprocal crosses over week 3 to week 43 of first lactation .....	94
Table 5.5. Least squares means for week to positive weekly energy balance, week to total cumulative energy balance, total energy balance, and total energy balance at week 21 for first lactation Holstein, Jerseys, and reciprocal crosses .....	95
Table 6.1. Incidence and percentages of displaced abomasums, mastitis, metritis, ketosis, and pregnancy in the first 100 days in first lactation Holsteins, Jerseys, and reciprocal crosses .....	110
Table 6.2. Health disease incidences by days in milk (DIM) for displaced abomasums, mastitis, metritis, ketosis, for the first 100 days in first lactation Holsteins, Jerseys, and reciprocal crosses .....	111
Table 6.3. Probability of a greater chi square statistic for the response variables for DA, ketosis, mastitis, metritis in the first 100 days and pregnancy in the first 150 days in first lactation of Holsteins, Jerseys, and reciprocal crosses .....	112
Table 6.4. Probability of a greater F statistic for $EB_{15}$ and $EI_{15}$ on the first 100 days in first lactation of Holsteins, Jerseys, and reciprocal crosses .....	113

## LIST OF FIGURES

Figure 2.1. Schema of possible milk production system.....	30
Figure 3.1. Schematic of feed intake editing process.....	41
Figure 4.1. Frequency distribution of differences between observed and predicted DMI of first lactation HH, HJ, JH, and JJ breed groups using NRC (2001) DMI equation.....	66
Figure 4.2. Relationship between residual (observed minus predicted) and fat corrected milk (FCM) for DMI for the four different breed groups HH, HJ, JH, and JJ using the NRC (2001) model.....	67
Figure 4.3. Graph of effect of age at calving on predicted dry matter intake (DMI) holding all other variables constant (relative to Holstein averages) using model A.....	69
Figure 4.4. Graph of days in milk effect on predicted dry matter intake (DMI) holding all other variables constant (relative to Holstein averages) using model A.....	70
Figure 4.5. Graph of minimum daily temperature effect on predicted dry matter intake (DMI) holding all other variables constant (relative to Holstein averages) using model A.....	71
Figure 5.1. Energy balance profiles by week of lactation (WOL) for each breed group for first lactation.....	96
Figure 6.1. Effect of age at calving on the probability of having an incidence of mastitis in the first 100 days of first lactation Holstein, Jersey, and reciprocal crosses.....	114
Figure 6.2. Effect of age at calving on the probability of conceiving in the first 100 days of first lactation Holstein, Jersey, and reciprocal crosses.....	115

# CHAPTER 1

## General Introduction

### 1.1 INTRODUCTION

Historically, dairy cattle have been intensely selected for production and conformation traits with minimal attention being given to health and fitness. The high productivity level in dairy cows has created increasing problems in fertility and health (Dunklee et al., 1994; Collard et al., 2000; Berry et al., 2003). Certain fertility and health problems have been associated with genetic improvement of production traits (Berry et al., 2003). The dairy industry in the United States has been dominated by Holsteins partially due to their high milk yield potential and has not been immune to the problems of decline in fertility and health. Energy balance has been linked to some of the health and fertility problems (Banos et al., 2006)

In early lactation, feed intake is often insufficient to meet the demands of milk production, which leads to negative energy balance in the cow. When a cow is in negative energy balance, body tissue is catabolized to meet the extra needs or energy output is decreased. Extended periods of negative energy balance or failure to replace lost body energy can lead to health problems, poor reproductive performance, and reduced production (Des Vries et al., 1999; Collard et al., 2000; Veerkamp et al., 2000). Studies of the genetic control of energy balance have shown a genetic component (Coffey et al., 2004; Friggens et al., 2007). There may be genetic differences in crossbreds and heterosis may also play a role.

Crossbreeding is a subject of interest in the dairy industry, and the number of crossbreds in the U.S. dairy population has increased over the last ten years (Weigel and Barlass, 2003; VanRaden et al., 2007). Several recent studies have used field data, focusing on calving traits, milk production traits, reproduction, and survivability. The Holstein cow retains her traditional advantage in fluid milk production, however, crossbreds have been found to have advantages in milk components, reproduction, and survivability (VanRaden and Sanders, 2003; Anderson et al., 2007). Few studies have

addressed feed efficiency, and with mixed results (Schwager-Suter et al., 2001; Heins et al., 2008), but there is very minimal literature for feed intake prediction equations and energy balance for crossbreds. Crossbred may differ from the purebreds for energy balance and energy balance terms (e.g. amount of energy partitioned to milk production), and research is needed in this area.

Designed crossbreeding trials were conducted in the 1960's and 1970's, but there have been very few designed crossbreeding experiments in the U.S. since that time. The most recent designed crossbreeding study was done in the late 1970's and continued to the early 1980's in Canada (McAllister et al., 1978). Most of the literature from designed crossbreeding experiments has come from historical data, or overseas where crossbreeding is more prevalent. Designed crossbreeding experiments are rare due to the resources required to implement the experiment (e.g. cow numbers, land, facilities, and time). Designed crossbreeding experiments feature a more controlled environment (typically) than field data. Additionally, designed studies typically include both purebred parent breeds in addition to crosses. Purebreds are needed to estimate heterosis, maternal effects, and in some cases recombination losses (where backcrosses are made). Often, this is not possible in field studies, because both pure breeds seldom perform in the same environment as crosses, if they exist at all. Typically, crosses are from a Holstein dam and thus are sired by different bulls than the purebred Holsteins.

The following chapter investigates literature on the topic of crossbreeding, feed intakes, energy balance, and modeling energy balance. Subsequent chapters discuss the designed crossbreeding project using first lactation Holsteins, Jerseys, and reciprocal crosses. The objectives were to investigate feed intakes, energy balance, and health and fertility in the different breed groups.

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## CHAPTER 2

### Literature Review

#### 2.1 CROSSBREEDING

Researchers have been interested in improving lifetime economic efficiency tools including mating and selection schemes. McDowell (1982) found that beneficial heterosis existed for many economically important individual traits, but also found that those benefits were not large compared to breed additive merit. One of his conclusions was “Crossbreds may not exceed the best purebred for any single trait, yet the net economic merit of the crossbred may be superior to purebreds when all the traits affecting or influencing net merit are considered”. Many studies have found benefits in crossbreeding (McDowell, 1982; Ahlborn-Brier and Hohenboken, 1991; Touchberry, 1992; Heins et al., 2006a,b,c). In these studies, overall yield in milk production was not deemed beneficial, but rather a combination of advantages in other traits. Touchberry (1992) observed in the Illinois study of 1949 to 1969 that “measures of survival, growth, milk yield, and reproduction were appropriately combined into an index of income produced by cows and on a basis of income per lactation crossbreds exceeded purebreds by 14.9%.”

Field studies have reported estimates of favorable heterosis for milk production in crossbred dairy cows. In New Zealand, Ahlborn-Brier and Hohenboken (1991) found that the F1 cross of Holstein by Jersey had a favorable heterosis effect of 6.1% for milk production and 7.2% for fat yield. The study found an individual breed effect that favored the Holsteins in milk yield, however, the F1 cross (both Jersey by Holstein (JH) and Holstein by Jersey (HJ)) exceeded the pure Holstein in fat percent. This is consistent with the findings of VanRaden and Sanders (2003) where protein yield of Brown Swiss by Holstein (BH) equaled the Holstein, and the fat yields of JH and BH were higher than those of the pure Holstein. They found favorable heterosis of 3.4%, 4.4%, and 4.1% for milk yield, fat yield, and protein yield, respectively. Heins et al. (2008a) reported that JH crosses did not differ from the Holsteins for fat production, but had significantly lower milk production.

There is evidence that crossbreds have a longer productive life in a dairy herd. VanRaden and Sanders (2003) reported that crossbreds lasted as long as or longer than the Holsteins with a 1.2 % heterosis for productive life. Other studies support this, but found higher heterosis of 9% (Hocking et al., 1988). Heins et al. (2006c) reported that crossbreds survive longer in herds. Several studies have indicated that crossbreds have fewer health and lameness issues than purebred Holsteins, which are beneficial to longevity (Heins et al., 2006c; Anderson et al., 2007).

The survivability of crossbreds in herds seems to be linked to having fewer days open than the purebred Holstein. Crossbreds have an advantage in reproductive performance. Heins et al. (2008a) found that JH had 23 less days open than contemporary purebred Holsteins. Dechow et al. (2007) reported that first lactation BH had a significantly lower days open (113) than either the pure Holsteins (130) or Brown Swiss (137). In addition, Dechow et al. (2007) found that crossbreds had 12.3 less days open over all lactations. These results are consistent with a 1968 study which found that all crossbred groups averaged fewer days open than all purebred groups (McDowell and McDaniel, 1968). Anderson et al. (2007) found in a pen study of Jersey-Holstein crosses that services per conception were 0.8 times that of the Holstein. The same study found that the crosses had 22 days less open, and a 6% increase in 21-day pregnancy rate. A study by McAllister et al. (1994) found that F1s produced 1.28 replacements for every F1 female born in comparison to the purebred which produced only 0.70.

There is evidence of advantages in calf survivability with crossbreds. A study by Maltecca et al. (2006) showed that calves from crossbred sires had less perinatal mortality than those from Holstein sires. The same study found that female crossbred calves had less mortality in the preweaning phase. Additionally, they found that the crossbred calves had less incidence of scours than their purebred counterparts. Heins et al. (2006b) found increased calving ease and reduced stillbirths to be advantages of crossbreds over the purebred Holstein.

There has been very little reported in the literature on body conformation traits of crossbreds. A study by Heins et al. (2008a) found that JH were shorter and weighed less but had a higher body condition score (2.8 vs. 2.7) than Holstein counterparts. In addition, the study found no statistical difference for rear udder height and width, and teat

length. However, the study found that crossbreds had less udder clearance and wider front teat placement. The difference in udder clearance could be related to stature because the crossbreds were shorter and therefore would be expected to have less udder clearance.

There are some concerns with crossbreeding. VanRaden and Sanders (2003) found a small and positive heterosis value for somatic cell count (which is detrimental) but can be explained as the increased yield may also cause an increase in the amount of stress placed on the udder. In addition, Weigel and Barlass (2003) found that marketing the bull calves of crossbred animals was difficult. Another concern is the salvage value of the crossbred cow due to smaller body size, but this would depend on the cross (e.g. a Brown Swiss by a Holstein would be at least as big as a Holstein). Certain crosses could cause lack of uniformity (size differences) in the milking herd which would make it more difficult to manage (Weigel and Barlass, 2003). Furthermore, the crossbred does not give as much fluid milk as the Holstein.

There is evidence that crossbreds can perform quite well on an economic basis. VanRaden and Sanders (2003) found that the net and cheese merit for both the JH and BH were higher than the purebred Holstein, however, the fluid merit was higher for the pure Holstein. Anderson et al. (2007) found that JH had an income over feed cost per day per cow that was \$0.42 less than their Holstein counterparts, but when accounting for days open, health disorders, and culling the income over feed cost was \$0.05 higher for the JH than the Holstein.

In May 2007, the United States genetic evaluation system switched to an all-breeds model which included crossbred animals in the national evaluations (VanRaden et al., 2007). The current number of crossbred dairy cows is about 10,000 with complete records with a birth year of 2001 – these are cows (VanRaden et al., 2007). This number exceeds the number of purebreds of the smaller breeds, and accounts for about 1% of animals in the current US genetic evaluation systems. Currently, New Zealand, the Netherlands, and the United States use an all-breed evaluation in their dairy genetic evaluation systems.

The number of crossbred cows has increased over the last few years and dairy producers perceive that crossbreeding has benefits (Weigel and Barlass, 2003). However,

the same authors stated “further research is needed regarding specific heterosis estimates for functional traits in crosses involving each of the major dairy breeds” as there is very limited information in current literature on estimates of heterosis and even less on specific breed crosses.

Crossbreeding has been shown to have advantages in milk component traits, fertility, survival, and calving ease, and could potentially be advantageous in feed efficiency and energy balance. Feed efficiency is of importance because feed is one of the largest cost of a dairy enterprise. Energy balance is important to the dairy industry because it has been linked with reproductive and health problems that have been of growing concern among dairy producers.

## **2.2 FEED EFFICIENCY AND ENERGY BALANCE**

Several different definitions of feed efficiency have appeared in the literature. Blake and Custodio (1984) defined feed efficiency as the rate of converting dietary nutrients to milk after adjusting for nutrients supplied by catabolism. Others have described feed efficiency as a ratio of feed energy and a form of milk energy such as milk production/ total digestible nutrients (Wang et al., 1992), energy content of milk/ net energy intake (Schwager-Suter et al., 2001), or energy-corrected milk/ dry matter intake (Heins et al., 2008b).

Blake and Custodio (1984) emphasized the need to look at both genetic and environmental factors for feed utilization and they suggested possible relationships between the two (Figure 2.1). The figure illustrates the impacts that genetics and environment can have on appetite, body size, milk yield, and tissue balance. For example, appetite is partially driven by body size, days in milk, and milk yield as phenotypic and environmental relationships. There are also genetic relationships that may drive appetite. There are genetics for appetite itself, as well as potential genetic correlations of body size and appetite, appetite and tissue balance, and appetite and milk production, all of which could influence appetite. Additionally, all of these factors may not influence appetite in the same direction. For example, there could be a negative genetic correlation that could be masked by a positive environmental correlation.

Veerkamp and Emmans (1995) concluded that it was very difficult to detect genetic variation in net efficiency (due to small numbers in studies and detailed recording), however, there were most likely genetic differences between cows in how they allocated energy to production and tissue balance. In addition, Veerkamp (1998) found that estimates from field data suggest that there are some differences in genetic variation in partitioning of energy to tissue repletion and production. Veerkamp (1998) concluded that the most important components to improve feed utilization by genetic selection are capacity for feed intake, energy needed for yield, maintenance, body condition changes, and any differences in partitioning among these components.

A study conducted at the Animal Breeding Research Organization in the 1970's in Edinburgh, Scotland examined differences between the efficiency of high and low production lines. The study used high and low genetic lines of Holsteins and Jerseys to investigate efficiency and performance traits. The study found that the high genetic line progeny for Holsteins lost more weight during lactation and gained less weight from calving to calving than the low production genetic line (Gibson, 1986). The Jersey comparisons had difficulty finding statistical significance partially due to a very low number of Jerseys in second lactation. The high genetic line for Jerseys numerically gained more weight from calving to calving which was the opposite of the Holstein findings. In addition, they found that the Friesians consumed 18% more energy than predicted and the Jerseys consumed 23% more than predicted indicating that requirements were underestimated in both breeds.

Gibson (1986) suggested that there were differences between breeds in the relationship of yield and associated body traits (i.e. body weight, body weight loss in early lactation, hip heights). Gibson (1986) demonstrated the high genetic line had a greater efficiency of converting food to milk when fed ad libitum. The study found that Holstein-Friesians were more efficient in converting food to milk energy. However, the methods employed could have favorably biased Holstein-Friesians (due to policies in the study on termination of lactation and rebreeding protocol) and even a small adjustment in favor of the Jerseys could change the results. Blake et al. (1986) found no differences in feed efficiencies between Holsteins and Jerseys, and concluded that the two breeds similarly converted nutrients into milk. The measure of gross efficiency was defined as

the energy in the milk divided by the total energy consumed. Gross energy doesn't differentiate between the maintenance, production, and body tissue gain or loss, all of which could have different partial efficiencies (Veerkamp and Emmans, 1995).

There have been a few studies reported in the literature that have investigated feed efficiency with crossbreds and the purebred Holstein ( McDowell and McDaniel, 1968; Wang et al., 1992; Schwager-Suter et al., 2001; Heins et al., 2008b). Heins et al. (2008b) and Wang et al. (1992) found that the crossbreds did not differ from the purebred Holsteins for feed efficiency (where feed efficiency was defined as energy-corrected milk divided by dry matter intake). However, other studies have found that crossbreds had a higher feed efficiency (where feed efficiency was defined as energy produced / energy consumed) than the purebreds (McDowell and McDaniel, 1968; Schwager-Suter et al., 2001).

Energy balance is the difference in energy a dairy animal consumes in feed and body usage of the energy for growth, maintenance, milk production, and reproduction. If there is a negative energy balance, stored body fat and tissue are mobilized to meet the extra needs or energy output in functions not explicitly defined such as reduced activity. High producing dairy cows cannot usually eat enough in early lactation to maintain positive energy balance. Extended periods of negative energy balance could lead to health problems, poor reproductive performance, reduced production, and may lead to early culling or death. The relationship could also go the other way where early postpartum diseases may reduce appetite which leads to lower production.

A study in Norway between 1978 and 1986 investigated the genetic parameters of feed conversion (Svendsen et al., 1993; Svendsen et al., 1994). The study used 353 cows from 20 different sires; all sires used were 1.5 additive genetic standard deviations above the average young sire for milk production. The first study found a heritability of 0.14 and 0.06 for energy balance in the first and second trimester of lactation, respectively (Svendsen et al., 1993). The second study found heritability of energy balance to range from 0.03 to 0.38 across all stages of the lactation (Svendsen et al., 1994). They found moderate to high correlations for energy balance between the periods ranging from 0.54 to 1.0 (Svendsen et al., 1993). They did not, however, find any additive genetic variance

for residual energy intake which was defined as energy balance adjusted for catabolism or anabolism (Svendsen et al., 1993).

A large energy balance study was conducted in the experimental herd at the Langhill Dairy Cattle Research Center Herd in Scotland between 1990 and 2002. The study included the first three lactations of 444 Holstein cows and feed intakes were collected over 12 years. Banos et al. (2005b) found that total body energy content at week five of the first lactation had a moderate genetic correlation of 0.60 to 0.70 with the same measurement in second and third lactations. In addition, the project compared high and low genetic lines of Holsteins on high and low concentrate diets. They found that cows selected for high production lost more body lipid stores than cows selected for average milk production regardless of the diet and concluded that selection for high yield predisposed cows to use body reserves to support production (Coffey et al., 2004). The work also showed that some cows were able to recover the lost body energy before the end of lactation or in the dry period whereas others could not (Coffey et al., 2003).

Wall et al. (2007) studied first lactation Holstein dairy cows in the UK and estimated daily breeding values (using random regression) for various body energy traits. Comparisons of bull daughters showed that substantial genetic variation existed for cumulative energy balance (CEB) (through the entire lactation). This would indicate that daughters of some sires can be in chronic negative energy balance whereas daughters of other sires may be in positive energy balance and able to store reserves for next lactation. Coffey et al. (2003) reported predicted breeding values for energy balance for sires with daughters in the Langhill experiment. They concluded that some sires with high genetic merit for yield may have daughters with body tissue mobilization profiles associated with poorer health and fertility, therefore leading to higher costs. Coffey et al. (2003) accounted for this “cost” by correcting the yield for body tissue lost and deducted milk yield from the breeding value in an amount equivalent to the amount of energy the body lost. The results were that an overall ranking of the sires before accounting for the cost of body tissue lost and after accounting for the cost of body tissue lost were very similar (correlation of 0.98), however, several sires changed drastically. One sire moved down 355 positions (out of 1240) on the net merit ranking chart.

Collard et al. (2000) studied the effects of energy balance on health traits. The study had individual feed intakes, health, and reproductive data on 140 multiparous Holstein dairy cows at the Agriculture and Agri-Food Canada Dairy Research and Development Centre in Lennoxville, Quebec Canada. The health traits were subdivided into five main categories including mammary, locomotive, laminitis, digestive, and reproductive. There were significant residual correlations (correlations between the residuals of the different models) specifically with energy balance and locomotive problems and energy balance and digestive disturbances. There were also significant differences between the mean energy balance for cows affected by diseases verses cows that were not affected by diseases for locomotion, laminitis, digestive, and reproductive. Another component of the study investigated the genetic relationship of energy balance in first lactation with udder health traits. Banos et al. (2006) found significant genetic correlations of up to -0.18 for energy traits (BCS, cumulative energy balance, energy content) at weeks greater than three in first lactation and somatic cell count in the first two lactations.

Feed efficiency and energy balance are both traits that are receiving more attention in the literature as of late. Evidence suggests that there is additive genetic variance for energy balance. Feed efficiency has had mixed results with respect to differences between breeds. A difficulty with both of these measures is getting accurate feed intake information for dairy cows.

### **2.3 FEED INTAKES**

Feed intakes, feed efficiency, and energy balance have a very intimate connection. Calculated net energy balance has been shown to be more dependent on feed intake than increases in milk production (Villa-Godoy et al., 1988; Zureck et al., 1995). In addition, Heuer et al. (1999) found that differences in net energy balance were in part explained by differences in feed intakes. A crucial component in calculating energy balance is predicting and or measuring feed intakes. Facilities, labor, cost, and feeding practices are a few of the reasons measuring feed intakes individually is challenging. Because of the difficulty of measuring feed intakes, only a few studies have large amounts of information to accurately predict feed intakes.



Intake prediction equations are critical for ration balancing as well as for various nutritional management decisions. They may be particularly important for smaller herds where scale-equipped mix wagons may not be used and total intakes are unknown. Historically, feed intake prediction equations were derived from data on Holstein cows, and there are limited studies in the literature on other breeds. The NRC (2001) dry matter intake (DMI) prediction equation is designed specifically for the Holstein cow. The NRC (2001) used 25 different papers with 100 different diets with 5,962 first lactation cow weeks and 11,125 later parity cow weeks to determine the prediction equation. Data was used from 1992 to 2000 from papers published in the Journal of Dairy Science. All of the papers except two used Holstein cows. Furthermore, the NRC (2001) states “No published DMI data were available for the developing or modifying the current equation for use with breeds other than Holsteins”, and reference for Jersey prediction equations is to Holter et al. (1996). Roseler et al. (1997) stated “improved prediction equations for DMI are possible through the use of more descriptive databases, which include descriptions of feed, cow, management, and environmental conditions”.

Most prediction equations include cow variables that are easily measurable or are already measured by producers including milk yield, fat yield, days in milk, and some indication of body weight (NRC, 2001; Halachmi et al., 2004; Ellis et al., 2006). There have been criticisms of the NRC (2001) prediction equation because of its inadequacy of modeling cows in early lactation (Shah and Murray, 2006). Shah and Murray (2006) indicated that the difference between the model they suggested and NRC (2001) was due to the accounting for daily variation in dry matter intake verses weekly variation in dry matter intake. However, Ellis et al. (2006) found that when compared to other commonly accepted models, the NRC (2001) out performed other models for prediction of dry matter intake.

Numerous studies have shown that feed intake changes throughout lactation. The lowest dry matter intake occurs immediately after calving and increases thereafter. However, the rate at which voluntary intake increases from week 1 postpartum to week of peak of DMI ranges from 2 to 111% and may be affected by diet, body weight, and body condition of the cow (Broster et al., 1998). Several studies have shown that increases in voluntary feed intake lagged several weeks behind the increase in milk

production. However, diet can impact this relationship (Ingvarlsen and Andersen, 2000). Intake of a first lactation cow is around 80% of that of a multilactation cow in the first part of lactation (Jarrige, 1986).

Current literature does not address crossbreed or breed differences for feed intakes. There is minimal literature on crossbreed and non-Holstein breeds for feed efficiency and energy balance. Feed intakes, feed efficiency, and energy balance could all potentially be influenced by breed, and warrants further investigation.

## **2.4 ANALYSIS OF LONGITUDINAL DATA**

Biologically, genes are activated and deactivated as animals age. This in turn could cause changes in physiology and performance over an individual's lifetime. In livestock industry settings (cattle, swine, poultry, and fish), traits that are repeatedly measured at various times during the animal's life are known as longitudinal traits and such measurements produce longitudinal data (Meyer and Hill, 1997; Schaeffer et al., 2000). Longitudinal data can be conceptualized as a function plotted over a continuous scale (Kirkpatrick and Heckman, 1989). Some examples of these traits are body weights, body lengths, milk production, feed intake, fat deposition, and egg production. Age can be recorded at a variety of intervals: year, month, week, day, or more refined units which result in a continuous range of points of time when an animal could be measured for a trait. Such traits have been called infinitely dimensional traits (Schaeffer, 2003).

Historically, the simplest way to analyze longitudinal data has been to treat the measures as repeated records on the same animal in a univariate mixed model (Ott and Longnecker, 2001). The univariate mixed model assumes that the observations have a constant variance and a common correlation with each other (Jennrick and Schluchter, 1986). However, the assumption of constant variance for a univariate repeatability model does not hold where individual variances change over time of measurement (Meyer and Hill, 1997). This typically happens in cases when repeated records change in a more or less fixed pattern such as a growth, lactation, or egg production curve. In these instances, a more complex model should be utilized. One way longitudinal data is analyzed is with a multivariate approach.

### 2.4.1 Multivariate Approach

Henderson (1984) developed a method of estimation that was shown to have the properties of Best Linear Unbiased Prediction (BLUP). BLUP can be considered an extension of the traditional selection index method with the advantage of allowing for simultaneous estimation of breeding values and adjustment for systematic environmental effects. With proper models, the method also accounts for genetic differences between herds and generations. Best Linear Unbiased Prediction is a family of statistical models, mathematical representations of animal performance that include various genetic and environmental effects that are used to obtain genetic prediction (Bourdon, 1997). The basic model equation with  $n$  total number of records and  $s$  individuals that will have breeding values estimated for  $t$  traits is

$$\mathbf{y} = \mathbf{X}\mathbf{b} + \mathbf{Z}\mathbf{u} + \mathbf{e} \quad [1]$$

where  $\mathbf{y}$  is vector of observations with the dimensions of  $(n \times 1)$  with phenotypic observations,  $\mathbf{X}$  is a  $(n \times r)$  incidence matrix for the  $r$  fixed effects,  $\mathbf{b}$  is a  $(r \times 1)$  vector for the  $r$  fixed effects,  $\mathbf{Z}$  is a  $(n \times s \times t)$  incidence matrix for the additive genetic effects,  $\mathbf{u}$  is a  $(s \times t \times 1)$  vector with additive genetic effects (breeding values) for the  $s$  animals to be evaluated for the  $t$  number of traits, and  $\mathbf{e}$  is an  $(n \times 1)$  vector of error terms for the  $n$  records. Multiple trait BLUP can be used for longitudinal data when observations can be clustered into a small number of like groups such as birth weight, weaning weight and yearling weight.

Wiggans and Goddard (1997) proposed using a multivariate (multiple-trait) model for the analysis of test day records of milk volumes, fat and protein percentages in dairy cattle where observations for each test day of the cow were treated as unique traits with correlations relating each “trait” to other “traits” recorded on other days in lactation. For example, the fat percent on test day one was treated as a separate but correlated trait to fat percent on test day two.

Pander et al. (1992) analyzed data from British Holstein-Friesians and calculated genetic parameters for each test day as a separate trait for milk yield; fat and protein yield; and fat and protein percent. Individual test day heritabilities ranged from 0.27 to 0.43 for milk yield, 0.16 to 0.34 for fat yield, 0.22 to 0.33 for protein yield, 0.11 to 0.48 for fat percent, and 0.21 to 0.43 for protein percentage, with the lower heritabilities

coming from the early stages of the lactation. The genetic correlations between records of respective lactation traits were high ranging from 0.76 to 0.99, and were highest during mid-lactation. They found estimated variance components for test records in an animal model, which considered multiple traits over multiple lactations using restricted maximum likelihood (REML) methodology. Vargas et al. (1998) found that heritabilities for traits in later parities were slightly higher than those from earlier parities. Both Vargas et al. (1998) and Pander et al. (1992) found that heritabilities were highest for mid-lactation records relative to earlier or later days in milk.

#### 2.4.2 Random Regression Approach

The use of a mean or predetermined function as covariates with the individual animal having its own random function is known as random regression (Henderson, Jr., 1982; Jennrich and Schluchter, 1986; Schaeffer, 2003). Using random regression, a function that applies to all cows can be fitted using covariates, and then each animal's random coefficient is explained by the deviation of that animal's individual function from the mean. The model equation for the form of random regression that uses the mean with each animal having its own random function is:

$$\mathbf{y} = \mathbf{X}\mathbf{b} + \mathbf{Z}_u\mathbf{u} + \mathbf{Z}_p\mathbf{p} + \mathbf{e} \quad [2]$$

where  $\mathbf{y}$  is a vector of longitudinal data observations on the animals (e.g. weights at different ages),  $\mathbf{X}$  is the incidence matrix which relates the observations to fixed effects and fixed regression coefficients,  $\mathbf{b}$  is a vector of fixed effects (and perhaps fixed regression coefficients),  $\mathbf{Z}_u$  is the incidence matrix of covariates relating observations to additive genetic random regression coefficients,  $\mathbf{u}$  is the vector of random additive direct genetic regression coefficient for each animal,  $\mathbf{Z}_p$  is the incidence matrix of covariates relating observations to permanent environmental random regression coefficients,  $\mathbf{p}$  is the vector of random permanent environmental regression coefficients for each animal,  $\mathbf{e}$  is a vector of temporary environmental effects for each observation. The variances for this random regression model are

$$\text{var} \begin{bmatrix} \mathbf{u} \\ \mathbf{p} \\ \mathbf{e} \end{bmatrix} = \begin{bmatrix} \mathbf{A} \otimes \mathbf{G} & 0 & 0 \\ 0 & \mathbf{I}_1 \otimes \mathbf{P} & 0 \\ 0 & 0 & \mathbf{I}_2 \sigma_e^2 \end{bmatrix} [3]$$

where:  $\mathbf{A}$  is Wrights numerator relationship matrix,  $\mathbf{I}_1$  is the identity matrix with dimensions equal to the total number of animals with at least one record,  $\mathbf{I}_2$  is the identity matrix with the dimensions equal to the total number of observations.  $\mathbf{G}$  is the genetic (co)variance matrix for the random additive direct genetic regression coefficients,  $\mathbf{P}$  is the permanent environment (co)variance matrix for the random permanent environmental regression coefficients with dimensions equal to the number of animals,  $\sigma_e^2$  is the temporary environmental variance and  $\otimes$  is the Kronecker product. Other fixed and random effects can be added to the model. The mixed model equations are represented as

$$\begin{bmatrix} \mathbf{X}'\mathbf{R}^{-1}\mathbf{X} & \mathbf{X}'\mathbf{R}^{-1}\mathbf{Z}_u & \mathbf{X}'\mathbf{R}^{-1}\mathbf{Z}_p \\ \mathbf{Z}_u'\mathbf{R}^{-1}\mathbf{X} & \mathbf{Z}_u'\mathbf{R}^{-1}\mathbf{Z}_u + \mathbf{A}^{-1} \otimes \mathbf{G}^{-1} & \mathbf{Z}_u'\mathbf{R}^{-1}\mathbf{Z}_p \\ \mathbf{Z}_p'\mathbf{R}^{-1}\mathbf{X} & \mathbf{Z}_p'\mathbf{R}^{-1}\mathbf{Z}_u & \mathbf{Z}_p'\mathbf{R}^{-1}\mathbf{Z}_p + \mathbf{I} \otimes \mathbf{P}^{-1} \end{bmatrix} \begin{bmatrix} \hat{\mathbf{b}} \\ \hat{\mathbf{u}} \\ \hat{\mathbf{p}} \end{bmatrix} = \begin{bmatrix} \mathbf{X}'\mathbf{R}^{-1}\mathbf{y} \\ \mathbf{Z}_u'\mathbf{R}^{-1}\mathbf{y} \\ \mathbf{Z}_p'\mathbf{R}^{-1}\mathbf{y} \end{bmatrix} \quad [4]$$

where  $\mathbf{R}$  is the (co)variance matrix for the residuals.

There are definite advantages to random regression methods for growth in the swine industry. Huisman et al. (2002) used random regression in pigs to select on growth and feed intake patterns and found that the largest increase in accuracy of selection is achieved through using random regression where all weight measurements are used. Huisman et al. (2002) found that when weights are modeled as a function of age, weights do not have to be adjusted for age, and unadjusted ages result in more accurate predictions by 2 to 3% over the multivariate model.

Random regression can also be used to determine environmental parameters, encountered by animals, in the dairy industry. Calus et al. (2003 and 2005) used random regression on environmental parameters to investigate genotype by environment interactions. They used random regression with an environmental parameter in a covariance function. This has the advantage that environments are treated as a continuum, rather than a set of arbitrarily defined groups of the data. Milk production average of the herd or calving interval are examples of continuous environmental effects that impact milk production.

Fish breeders have found application for random regression. McKay et al. (2002) looked at the growth curves of rainbow trout (*Oncorhynchus mykiss*) to obtain heritability estimates and found that heritability of weights of trout vary, depending on age, strain,

and population structure. He concluded that random regression was useful in evaluating individual growth data for a rainbow trout and selection for improved growth would be most efficient just after one year of age because that is where heritability was at the highest point of 0.49.

Random regression techniques have proved successful in beef cattle as well. Meyer (2004) used three beef cattle datasets to quantify the potential increase in accuracy from using random regression models. The first data set included animals from an experimental herd in which the animals were weighed monthly. Data sets two and three represented field data with less frequent weights and additional data increased available records by 50 or 100%. The data sets used in the study maintained the original pedigree structure and replaced the original observations with simulated values. Meyer found that the random regression model was up to 5.9% more accurate than the multiple-trait model when applied to the data set where every animal had at least four weights. Even in the worst-performing simulated field data set, the increase in accuracy was 1.5-1.7% over the multiple trait model. The added accuracy was due to more appropriate modeling of genetic parameters, avoiding preadjustment for age, and the additional data. Robbins et al., (2005) also used random regression techniques to model the growth of Gelbvieh cattle with splines and Legendre polynomials and compared results to a multiple-trait model. They reported that both splines and cubic Legendre polynomials (provided they were diagonalized) gave practical and more flexible evaluations and a theoretically more sound alternative to the multiple-trait method.

Random regression has been useful to determine energy balance of dairy cattle (De Vries et al., 1998; De Vries and Veerkamp, 2000; Coffey et al., 2002; Wall et al., 2005; Wall et al., 2007). The studies used random regression techniques to obtain animal solutions. The animal solutions were then used to calculate the daily phenotypic values for the traits of interests. Coffey et al. (2002) and Wall et al. (2005) used random regression for milk production, live weight, feed intake, energy intake, and condition score. A curve, as for infinitely dimensional traits, was created for each animal for each trait and energy balances on each day was calculated from the curves. Wall et al. (2007) used random regression to determine energy balance and breeding values at every day for type traits that specifically looked at angularity, chest width, body depth and stature.

Wall et al. (2007) then investigated the relationship of type traits and energy balance traits with respect to health and fitness traits. They found that the genetic correlation between the energy balance traits and the fitness traits was low and nonsignificant. There were significant genetic correlations between the type traits (body depth, chest width, and stature) and lifespan, somatic cell count, nonreturn rate and calving interval. De Vries and Veerkamp (1995) also used random regression on energy balance. They had measurements of all variables at every week and calculated energy balance by week and then used random regression on energy balance directly.

Random regression techniques do have their flaws. The advantage of using random regression models over the more traditional multiple trait models depends on how the random regression model is implemented (Bohmanova et al., 2005). For example, Nobre et al. (2003) found that the random regression model with Legendre polynomials had poor numerical properties, until reparameterized by diagonalization. Schaeffer (2003) cautioned that appropriate range of times or ages was critical in random regression. The estimation may be poor for records on the extreme ends of the trajectories where data is sparse (Meyer, 1999). An evaluation using a random regression model may have less accuracy than a multiple trait model if the parameters of the random regression are poor. Random regression models are also more susceptible to artifacts especially when estimating direct and maternal effects on animals that are missing records at given ages (Albuquerque and Meyer 2001; Nobre et al., 2003). However, this could be overcome by using a data set that has few missing traits and good connections between direct and maternal effects (Nobre et al., 2003.). Pool et al. (2000) found that random regression models did not predict the trajectory of the curve very well unless all data that was relevant to the trajectory was present in the data analyzed. Coffey et al. (2002) found results that supported this. They found nonsensical solutions when the data was truncated at 250 days in milk instead of 305 days in milk, because random regression needed data through the whole lactation to adequately predict records through the entire lactation.

Random regression has a practical application in several model situations. It has provided a way to investigate growth, lactation curves, and energy balance. In addition, random regression allows for unevenly spaced observations and missing observations and can produce a curve for all animals at all days. Random regression is a very practical

way to look at growth, lactation, and intake curves, provided that the data encompasses data from the entire curve.

To summarize, crossbreeding and energy balance are current topics in the dairy industry. Crossbreeding in dairy cattle has been shown to have advantages in a wide array of traits but has yet to be adequately tested for its effects on feed efficiency or energy balance. Animals express genetic differences in return to positive energy balance. There could be economic benefits from improved rates of return to positive energy balance. Random regression has shown to be useful in determining energy balance and could be a method employed to determine if there are differences between energy balance and the breeds.



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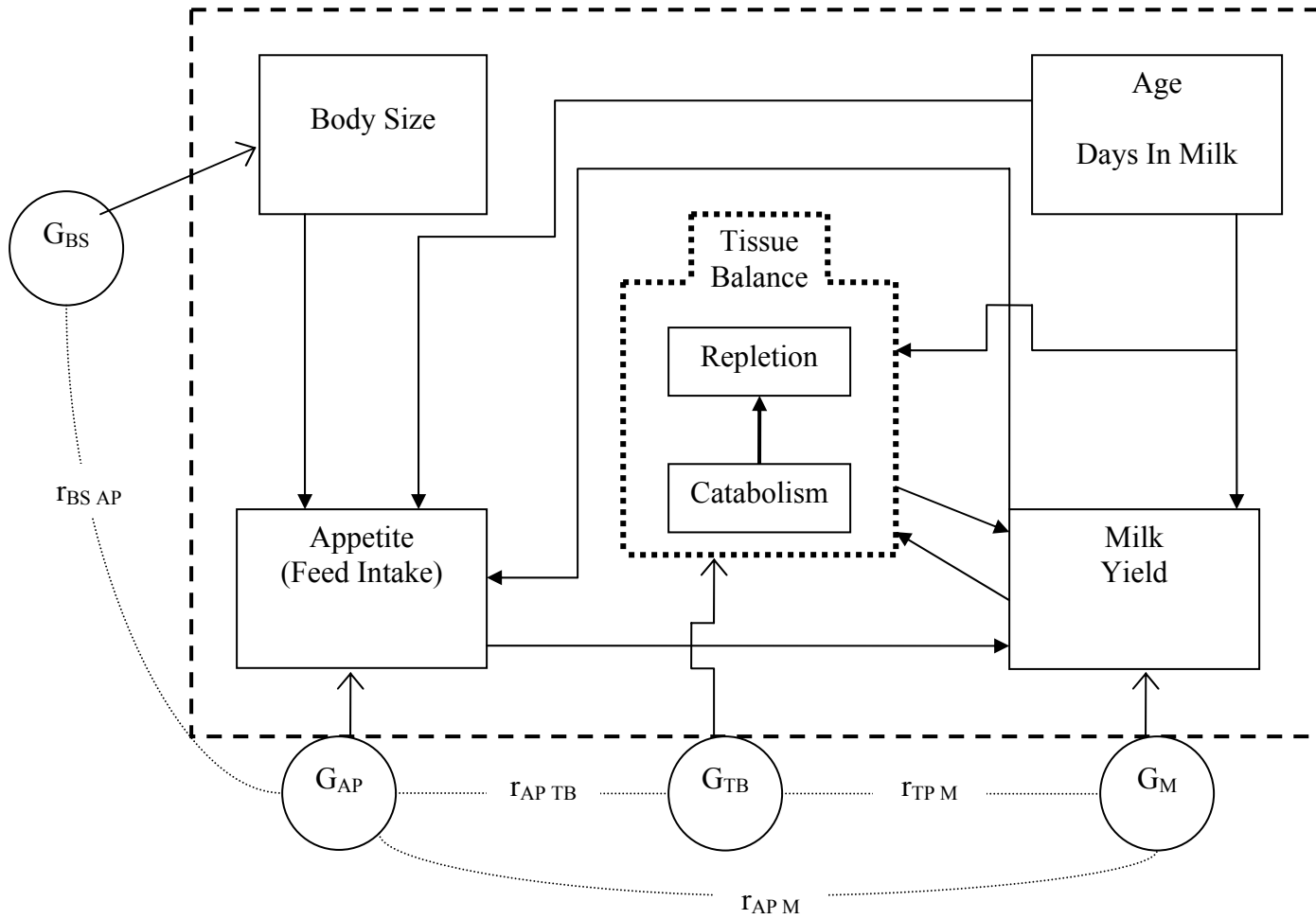
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**Figure 2.1** Schema of possible milk production system. Elements in the dashed-line box (----) represent phenotypic and environmental relationships (closed arrows), and genotypic associations (G, open arrows) lie outside (BS = body size, AP = appetite, TB = tissue balance, M = milk yield) adapted from Blake and Custodio (1984).



## **CHAPTER 3**

### **A Description of the Data**

#### **3.1 ANIMALS**

The crossbreeding project at Virginia Tech began in the fall of 2002. The study was designed as a classical diallel scheme with Holstein and Jersey foundation females mated to four Holstein bulls and four Jersey bulls to create JJ, HH, JH, and HJ breed groups (sire breed listed first). The four Holstein sires and four Jersey sires with corresponding genetic ranks within breed for the start (Feb., 2002) and end (April, 2008) of the project can be found in Table 3.1. The genetic rank was based on Net Merit which is an index that includes milk production traits along with other economically important traits. The average Holstein sire had a Net Merit rank of 75.5% and the average Jersey sire had a rank of 75% at the start of the project, however, by April of 2008 the Holsteins had an average rank of 41% and the average Jersey only had 26.5%. The Net Merit index has changed since the beginning of the project and the corresponding Net Merit on the current index using the Feb., 2002 proofs can also be found in Table 3.1. The drop in the average percentile rank was not ideal, because the intent was to compare the average Holstein sire with the average Jersey sire, and the Jersey sires were ranked lower within breed than the Holsteins. The two bulls with lowest percentile rank within breed were Jersey and the highest percentile ranking bull within breed was Holstein. This has the potential to bias group comparisons.

The foundation females were mated to heterospermic semen that consisted of a mix of one Holstein sire paired with one Jersey sire, and further details of the heterospermic study are explained by Kasimanickam et al. (2006). The heterospermic insemination caused the numbers in breed groups and sires to be unbalanced because certain sires inseminated more females. The Holsteins sired 76 project cows whereas the Jerseys sired 42. Sire by breed group numbers are in Table 3.2.

Breed groups were analyzed two different ways. Breed groups were examined as discrete variables; HH, HJ, JH, and JJ. Breed groups were also used to determine the type of genetic control by partitioning breed groups into percent additive Holstein genes, percent Holstein genes in dam of the cow (maternal component), and percent heterosis in

the cow. However, examining breed groups this way is not orthogonal if all three effects are considered at once, but there are orthogonal contrasts that allow for all effects to be considered. Table 3.3 illustrates the coefficients by breed group to determine the type of genetic control.

## **3.2 FEED INTAKES**

### *3.2.1 Collection of Feed Intakes*

Limitations of facilities, resources, and duration of the project restricted collection of feed intakes to cows in their first lactation. Banos et al. (2005) estimated the genetic correlation of first lactation body energy content at week five and the same week in later lactations to be between 0.6 and 0.7. Thus, results from first lactation studies are useful for inferences concerning later lactations.

Individual feed intakes were measured on first lactation cows in two-week time intervals out of every six week period (two weeks on, four weeks off) using the Calan<sup>TM</sup> door system (American Calan, Northwood, NH). Project cows involved in nutrition feeding trials that did not restrict intakes were also included in the study (total of four trials). Cows were fed a total mixed ration (TMR) to which they had been exposed prior to each intake period, so no adaptation time was required for adjustment to the TMR. Cows were fed ad libitum once a day with offered feed weighed one day, and refusals weighed the following day. Feed offered was adjusted so that refusal rates were approximately 10% on an as-fed basis. Forages, grains, and concentrates were submitted for nutrient analyses at least once during each trial period. As-fed intake, dry matter intake (DMI), and intake of net energy for lactation (NE<sub>L</sub> (Mcal)) were calculated daily for the project cows. Dry matter and NE<sub>L</sub> in the TMR were calculated using information from the forage testing laboratories of Cumberland Valley Analytical Services (Hagerstown, MD). The NE<sub>L</sub> calculations used for different forages and concentrates by Cumberland Valley Analytical Services can be found at <http://www.foragelab.com>.

Collection of feed intakes began in September of 2005 and continued through March of 2008. Each intake trial was comprised of approximately 30 cows ranging from 8 cows in September 2005 to 48 cows in July of 2007. All cows were housed in a single pen during the trial period regardless of breed. Cows were included in a trial period until

they were greater than 305 days in milk (DIM). A total of 26 trials were conducted with 9,971 unedited daily individual observations of feed intakes. Daily feed intake observations for each cow ranged from 12 to 223 with the average cow having 83 unedited feed intake observations.

### *3.2.2 Editing of Feed Intakes*

Feed intakes were edited in a stepwise manner. The first set of edits removed data collected during any equipment malfunctions including problems with a door, the cow transponder, or data ranger. Cows that were removed from a trial within the first three days (due to sickness or failure to adapt to using the door) were discarded for the entire trial period and observations on cows that were over 305 DIM were also removed. This could happen on the last few days of a cow's last trial. These edits reduced the initial data set by 103 observations to 9,868. Eight cows were removed from their first trial within the first few days due to illness or training problems; seven of those cows returned to the doors in the second trial period and acclimated to the doors. For these cows, the second trial was treated as their first trial period for the rest of the data edits. One cow never adjusted to the Calan doors and was removed from the study completely.

A second series of data edits was designed to ensure adequate adjustment time to the Calan doors. The first five days were discarded from the cow's first trial, which reduced daily feed intakes by 590 observations. The first two days of each subsequent trial were discarded which reduced the data set to 8,151 observations. In second and subsequent trials, cows were already trained to use the doors, and the first two days allowed them time to readjust to using the door or adjust to using a different door. To the extent possible, cows were assigned to the same door each trial, however, some moves were required.

A third round of edits was designed to identify cows that needed longer adjustment times and those that encountered other unknown problems. The first five days of intakes in each trial period were removed. For each cow-trial combination, the remaining days were used to calculate a mean and standard deviation (SD) of daily intake. These parameters formed a confidence interval for each cow-trial, using four standard deviations each side of the mean. The first five day's data was then added back

to the data set and the confidence interval was applied to identify outliers which were subsequently discarded. This step discarded 1.3% of the data leaving 8,042 observations on 118 cows. Figure 3.1 illustrates the editing of the feed intake data. The final observations by breed group are represented in Table 3.4.

### **3.3 MILK PRODUCTION**

All project cows were milked twice daily, with the exception of July 2006 in which all cows were milked three times a day. The daily milk weights were recorded by the Afifarm™ herd management software (S.A.E. Afikim, Kibbutz Afikim, Israel). In addition to the daily milk weights, DHIA milk samples were collected monthly and provided estimates of milk fat percent, protein percent, and somatic cell count (SCC).

Milk components and daily milk weights were then combined using the test day method and as explained by Wiggans and Goddard (1997). The test day model was chosen because all cows had milk components at every month. Milk weights (n = 32,150) were edited by partitioning the lactation into five stages of 60 days and from those stages, a mean and standard deviation were calculated within breed group within stage of lactation. Originally, records that were three standard deviations outside of the mean for breed group within stages were discarded. However using this method, five cows lost more than 20 daily milk weights and a total of 280 daily milk weights were discarded, a loss of data of 3% of the JJ data and over 2% of the JH data. The screening was expanded to four standard deviations, and no cow lost more than eight records. A total of 60 records were discarded with 24, 7, 18, and 11 for HH, HJ, JH, and JJ. No breed group lost more than 1% of the data. The intent was to exclude extreme data. There were a total of 32,090 edited records of daily milk production with 11,411, 9,092, 7,978, and 3,609 records for HH, HJ, JH, and JJ, respectively. Daily milk records from 10 to 305 DIM were used.

The NRC (2001) used fat corrected milk (FCM) to account for differences in the energy content of milk. However, adjustment assumes constant protein content. This study included different breeds, adding cow to cow variation in protein. Therefore,

energy corrected milk (ECM) was used. ECM was calculated using the equation from Tyrrell and Reid (1965) as:

$$\text{ECM} = 0.327 \times \text{milk kg} + 12.96 \times \text{fat kg} + 7.2 \times \text{protein kg.} \quad [1]$$

### **3.4 BODY WEIGHTS, HIP HEIGHTS, AND BODY CONDITION SCORES**

Daily body weights were recorded twice daily by the Afifarm<sup>TM</sup> herd management software (S.A.E. Afikim, Kibbutz Afikim, Israel) and were measured as the cow left the milking parlor. Body weights were used from 10 to 305 DIM. Weekly average body weights were used because of daily variation in body weights.

Body condition scores (BCS) were assigned using the 5 point system from 0 (thin) to 5 (fat) with increments of 0.25 as described by Wildman et al. (1982). The BCS was assigned to a cow on the basis of visual appraisal of tissue covering the spine and pelvic regions. Cows were assigned BCS at five-week intervals after calving until 305 DIM by a single evaluator. A total of 774 body condition scores were assigned to the project cows during the first 305 days of lactation with 272, 226, 177, and 99 records on HH, HJ, JH, and JJ.

Hip heights were measured at the same time BCS was scored. Hip heights were measure by a single evaluator and were recorded within 0.635 cm. A total of 741 hip heights were recorded with 245, 224, 175, and 97 HH, HJ, JH, and JJ.

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**Table 3.1. Rank for Net Merit (NM \$) within breed for Holstein and Jersey foundation sires in the Virginia Tech crossbreeding project**

NAAB <sup>1</sup>	Short Name	Feb. 2002 proofs, Feb. 2002 NM \$ equation	Feb. 2002 proofs, April 2008 NM \$ equation	April 2008 proofs, April 2008 NM \$ equation	Rank within breed using Feb. 2002 proofs and equation	Rank within breed using April 2008 proofs and NM \$ equation
Holsteins						
7H5112	Breton	372	191	220	64	41
7H5710	Dane	524	395	231	94	44
9H2344	Cooper	361	208	353	60	75
9H2315	Jasper	457	305	132	84	20
Jerseys						
7J424	Freedom	375	254	-63	76	01
7J442	Paramount	459	341	307	97	54
7J498	Elevation	353	232	96	67	11
7J472	Parade	341	219	272	60	40

<sup>1</sup>National Association of Animal Breeders animal number

**Table 3.2. Numbers of project cows by each sire within each breed group**

NAAB <sup>1</sup>	Sire Name	HH <sup>2</sup>	HJ	JH	JJ	Total
7H5112	Breton	11	6	0	0	17
7H5710	Dane	9	6	0	0	15
9H2344	Cooper	11	6	0	0	17
9H2315	Jasper	13	14	0	0	27
7J424	Freedom	0	0	7	5	12
7J442	Paramount	0	0	11	2	13
7J498	Elevation	0	0	7	4	11
7J472	Parade	0	0	4	2	6
Total		44	32	29	13	118

<sup>1</sup> National Association of Animal Breeders animal number

<sup>2</sup> sire breed by dam breed

**Table 3.3. Coefficients for proportion of additive Holstein genes, maternal Holstein genes, and heterosis in breed groups.**

Breed/Component	HH <sup>1</sup>	HJ	JH	JJ
Additive	1	0.5	0.5	0
Maternal	1	0	1	0
Heterosis	0	1	1	0

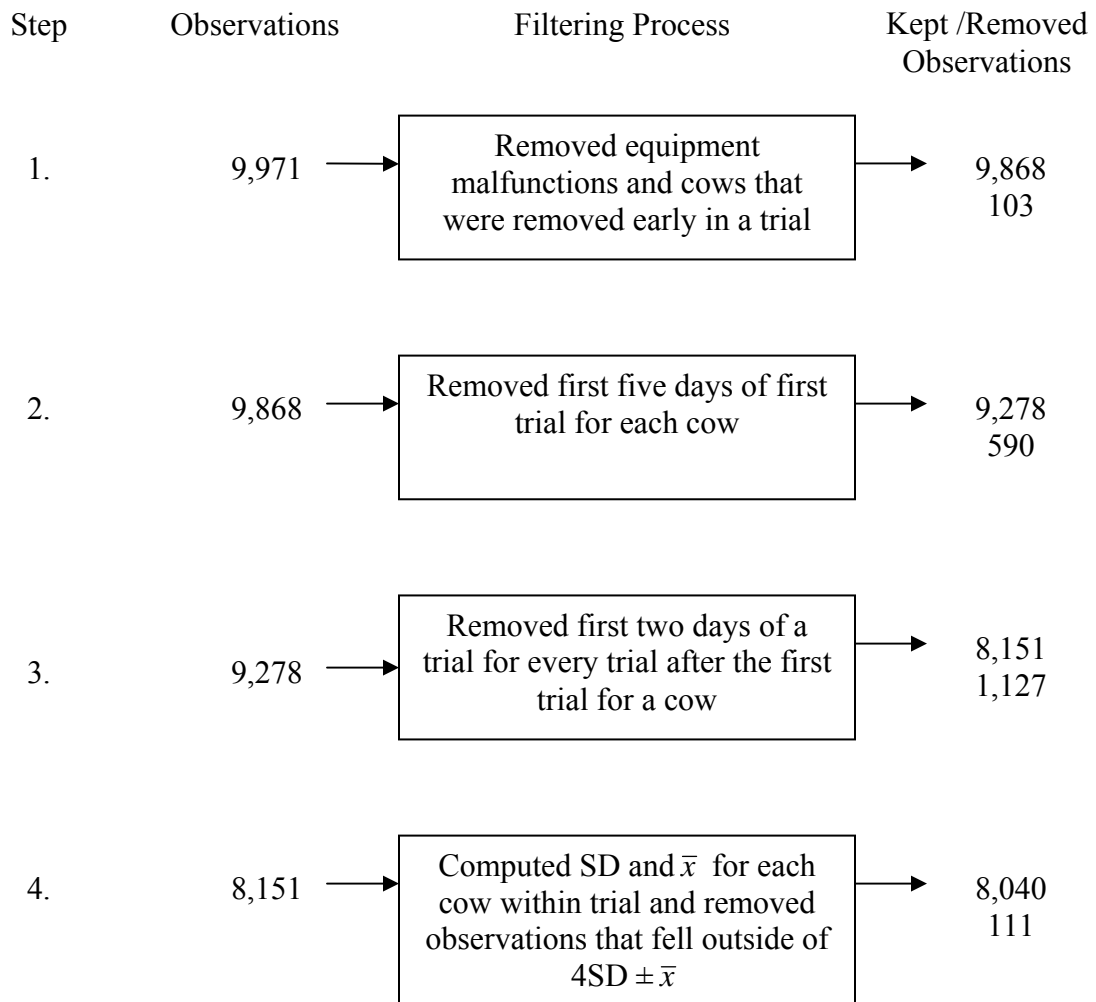
<sup>1</sup> sire breed by dam breed

**Table 3.4. Daily feed intake observations by breed group**

Breed Group	Frequency	Number of cows	Observations/cow
HH <sup>1</sup>	3,323	44	76
HJ	2,122	32	66
JH	1,828	29	63
JJ	767	13	59

<sup>1</sup>sire breed by dam breed

**Figure 3.1.** Schematic of feed intake editing process



## CHAPTER 4

### **Dry matter intake prediction equations for Holstein, Jersey, and reciprocal crosses in first lactation.**

#### **4.1 ABSTRACT**

The crossbreeding project at Virginia Tech began in the fall of 2002. Holstein and Jersey foundation females were mated to four Holstein bulls and four Jersey bulls to create JJ, HH, JH, and HJ breed groups (sire breed listed first). Collection of individual dry matter intakes (DMI) on first lactation cows began in September 2005 and continued through March 2008. DMI were measured in two week trials during every six week period (two weeks on, four weeks off) on cows less than 306 days in milk. A total of 7,727 daily DMI from 118 cows with 44, 32, 29, and 13 HH, HJ, JH, and JJ, respectively, were collected. The National Research Council (NRC) DMI prediction equation was used across breed groups to investigate differences in DMI predictions. Prediction equations were developed across breed groups and for each breed group separately using a backward elimination method. All equations contained adjustments for days in milk, days pregnant, and energy corrected milk. The NRC DMI model had a root mean square prediction error (RMSPE) of 2.21, 1.86, 2.00, and 1.64 kg/d for HH, HJ, JH, and JJ, with the HH and HJ being different from each other. The NRC under-predicted DMI for the HH and over-predicted for HJ, JH, and JJ with a mean bias of 0.17, -0.19, -0.02, -0.19 for HH, HJ, JH, and JJ. The regression of residual DMI on fat corrected milk (using the NRC model) was significant indicating a linear bias with respect to fat-corrected milk. Prediction equations developed from the data indicated no difference between the HJ and JH group in the model including all breed groups, so they were combined into one crossbred breed group. The all-breed group equations had significant breed group effects. Parameters that were different among the all-breed group equation, Holstein equation, and crossbred equation included coefficients associated with body weight, age at calving, and minimum daily temperature. The coefficient for body condition score was significant for the Holstein and Jersey equations but not for the crossbred equation. The

coefficient of determination for the equations ranged from 0.40 to 0.49 with a RMSPE ranging from 1.8 kg/d to 2.5 kg/d. The results indicate that breeds do differ in DMI even after accounting for body weight and milk production. Data were from a relatively small number of Jersey sired animals first lactation and results warrant further investigation.

(Keywords: crossbreeding, dry matter intake, feed intake)

## 4.2 INTRODUCTION

There have been an increasing number of crossbreds in the U.S. dairy population over the last 10 years (Weigel and Barlass, 2003; VanRaden et al., 2007). In fact, crossbreds outnumber all breeds except Holsteins and Jerseys in the United States (VanRaden et al., 2007). Current research on crossbreeding has mainly focused on calving traits, milk production, reproduction, and survivability. Some research has compared feed efficiency and feed intakes on purebred Holsteins to purebred Jerseys (Blake et al., 1986; Rastani et al., 2001), but information on dry matter intakes (DMI) or DMI prediction equations for crossbreds is very limited.

Dry matter intake prediction equations are important for the dairy industry. They are used for ration balancing, nutrient management, and may be especially important for smaller herds where scale-equipped mix wagons may not be used and total intakes are unknown. There are various dry matter intake (DMI) prediction equations in the literature (Roseler et al., 1997a,b; NRC, 2001; Shah and Murphy, 2006). However, these prediction equations were developed using data from Holsteins. The NRC (2001) states “No published DMI data were available for developing or modifying current equations for use with breeds other than Holsteins”. Holter et al. (1996) used Jersey cows for feed intake prediction equations, but only had Jerseys and no comparisons to Holsteins. This could be problematic for nutritionists and dairy producers because they would have to make a decision about how to adjust the equations for non-Holstein breeds. Scaling for body size and milk energy may be adequate to accommodate the breed differences, but the subject has received very little attention in the literature.

The objective of this study was to determine if there were important breed differences in DMI prediction equations for first lactation Jerseys, Holstein, and reciprocal crosses, managed together.

### **4.3 MATERIALS AND METHODS**

#### *4.3.1 Experimental Design*

The crossbreeding project at Virginia Tech began in the fall of 2002. The study was designed as a classical diallel scheme having Holstein and Jersey foundation females mated to four Holstein bulls and four Jersey bulls to create JJ, HH, JH, and HJ breed groups (sire breed listed first). The foundation females were mated with heterospermic semen that consisted of a mix of one Holstein sire paired with one Jersey sire. The first heifers from the project were born in June of 2003 and calved between June 2005 and February 2008. There were a total 118 cows with 44, 32, 29, and 13 HH, HJ, JH, and JJ, respectively. There were fewer Jerseys due to the low fertility on the four Jersey bulls that were selected for the project (Kasimanickam et al., 2006).

#### *4.3.2 Data*

Data contained daily DMI observations from first lactation Holsteins, Jerseys, and reciprocal crosses at the Virginia Tech dairy. Individual daily feed intakes were measured in two week time intervals out of every six week period (two weeks on, four weeks off) using the Calan™ door system (American Calan, Northwood, NH). Cows were fed a total mixed ration ad libitum once a day. Feed offered was weighed on one day, and refusals were weighed the following day. Feed offered was adjusted over time so that refusal rates were approximately 10% of the feed a cow was offered. Forages, grains, and concentrates were submitted for nutrient analyses at least once during each trial period. An “as-fed” intake was collected during the feed intake cycle and DMI was calculated from nutrient analyses and as-fed intake.

Intakes began in September of 2005 and continued through March of 2008. Each intake trial was comprised of approximately 30 cows ranging from 8 cows in September of 2005 to 48 cows in July of 2007. All cows were housed in a single pen during the trial period regardless of breed. Cows continued to be included in a trial period until



completion of 305 days in milk (DIM). A total of 26 trials were conducted including four nutrition trials that involved some project animals and did not restrict intakes. Total data included 9,971 unedited daily observations of feed intakes. Daily feed intake observations per cow ranged from 12 to 223 with an average of 83 unedited feed intake observations per cow.

Daily body weights (BW) and milk weights were recorded twice daily by the Afifarm™ herd management software (S.A.E. Afikim, Kibbutz Afikim, Israel). Body weights were measured as the cow left the milking parlor. Body weights and milk weights were used from 10 to 305 DIM. To account for large variation within daily BW, weekly average BW were used and were also converted to metabolic body weight ( $BW^{0.75}$ ).

DHIA records were taken monthly and provided estimates of milk fat percent and protein percent. Milk components and daily milk weights were then combined using the test day method as explained by Wiggans and Goddard (1997). Milk and components were used to determine energy in the milk. Energy-corrected milk (ECM) for each cow was calculated (Tyrrel and Reid, 1965) where:

$$ECM \text{ (kg)} = 0.327 \times \text{milk kg} + 12.96 \times \text{fat kg} + 7.2 \times \text{protein kg. [1]}$$

Four percent fat-corrected milk (FCM) was calculated for each cow (Gaines, 1928)

$$FCM \text{ (kg)} = 0.4 \times \text{milk kg} + 15 \times \text{fat kg. [2]}$$

Body condition scores (BCS) were assigned using the 5 point system starting from 0 (thin) to 5 (fat) in increments of 0.25 as described by Wildman et al. (1982). Cows were assigned BCS on a five week interval (from calving until 305 days in lactation) by a single evaluator. Hip heights to the nearest 0.635 cm were assigned by one evaluator at the same time as BCS was recorded.

Daily temperatures for the dates of the trials were obtained from the National Weather Service in Blacksburg, VA. The temperature information included minimum daily temperature (MINT), average daily temperature (AVT), and maximum daily temperature (MAXT). Days pregnant (DPREG) was determined from verified pregnant by a veterinarian and where applicable followed by subsequent calving.

#### 4.3.3 Data Edits

Daily feed intakes were edited for equipment malfunctions, adaptation time to the Calan doors, and removing cows that became noticeably sick during the trial. These edits decreased the DMI observations from 9,971 to 8,151. Dry matter intakes were further edited by calculating a confidence interval for each cow within each trial. Observations that fell four standard deviations (SD) outside of the mean were discarded. This reduced the data set by 1.3% to 8,042 daily intakes on 118 cows.

Milk weights were edited by partitioning the lactation into five stages of sixty days each and a mean and SD were determined within breed group within stage. Originally, daily milk yields that were three SD outside of the mean for breed within stages were discarded. However, using this method, five cows lost more than 20 records and 280 records were discarded. When the confidence interval was increased to four SD, no cow lost more than eight records in the lactation. A total of 32,090 edited records on daily milk weights were available. There were 11,411, 9,092, 7,978, and 3,609 records for HH, HJ, JH, and JJ, respectively. Sixty daily milk records were discarded with 24, 7, 18, and 11 for HH, HJ, JH, and JJ which was less than one percent for all breeds.

Dry matter intakes, BCS, BW, hip heights, MINT, MAXT, AVT, milk weights, milk components, ECM, and FCM were all combined into a final data set. Table 4.1 contains a detailed explanation of variables in the data set. Daily records that were missing data for any variable were discarded. The final data set consisted of 7,727 daily observations ranging from 7 to 177 on individual cows with an average of 65 daily observations per cow. Daily observations were 3,103, 2,077, 1,791, and 756 for HH, HJ, JH, and JJ, respectively. Means and ranges by breed group for each variable are in Table 4.2.

#### 4.3.4 Comparison of Breeds for NRC (2001) Model

The NRC (2001) model for DMI was used to determine if there were breed differences in the predictions of DMI. The model was defined as

$$\text{DMI(kg/d)} = (0.372 \times \text{FCM} + 0.0968 \times \text{BW}^{0.75}) \times (1 - e^{(-0.192 \times (\text{WOL} + 3.67))}) \quad [3]$$

where WOL was week of lactation. The observed daily DMI (O) for each cow and the predicted daily DMI (P) for the NRC (2001) equation were compared across breed groups using mean square prediction error (MSPE):

$$\text{MSPE} = \Sigma (O_i - P_i)^2 / n \quad [4]$$

where n = the number of pairs of predicted (P) and observed (O) DMI intake values.

MSPE can be partitioned into three components:

$$\text{MSPE} = (\bar{O} - \bar{P})^2 + S_p^2(1 - b)^2 + S_o^2(1 - r^2) \quad [5]$$

where  $S_o$  and  $S_p$  are variances of observed and predicted DMI,  $b$  is the slope of the regression of O on P, and  $r$  is the correlation coefficient of O and P (Meyers, 1990). The three components are due to mean bias, line bias, and random variation around the regression line. Mean bias can be utilized to test the adequacy of the model in this production environment whereas line bias is an indication of inadequacies in the structure of the model. MSPE and root mean square prediction error (RMSPE) have been used various times to evaluate feed intake prediction equations (Roseler et al., 1997a, b; NRC, 2001; Shah and Murphy, 2006). A general linear model, with a Scheffe adjustment, was used to determine if there were differences between breeds for the residuals.

#### 4.3.5 Prediction Equations

The NRC (2001) model for DMI makes no adjustment for breed so our data set was used to derive prediction equations with an adjustment for breed. The number of observations of daily intakes for all breed groups had a relatively lower number of observations than data used to develop the NRC (2001) prediction equations preventing an independent validation of the models. Several different equations were investigated. The goal was to develop models that included significant variables that were easy to measure or readily available. Two models were developed to include all breed groups. The two all breed group models differed in the way that breed group was partitioned. Breed groups were examined as discrete variables HH, HJ, JH, and JJ in one model (model A) and partitioned into percent additive Holstein genes, percent Holstein genes in the dam of the cow (maternal component), and percent heterosis in the cow in the other model (model b). Examining breed group influence as additive, maternal, and heterosis effects defined the way we have is not orthogonal if all three effects are considered at

once. Table 4.3 illustrates the coefficients for additive, maternal, and heterosis effects for each breed group based on the definition above. Additionally, a separate model for each breed group was developed.

The models were developed using variables that were significant and whose elimination caused a large reduction in coefficient of determination. Backward elimination using a  $P < 0.10$  provided the basis for variable inclusion. The variables in Table 4.2 (with square and cubic term) were considered for model inclusion.

## 4.4 RESULTS AND DISCUSSION

### 4.4.1 The NRC Model

The prediction accuracy for the NRC (2001) model (equation 3) was relatively high with the RMSPE and mean bias for all breeds being 2.62 kg/d and 0.01 kg/d, respectively. Table 4.4 shows the observed and predicted DMI using the NRC (2001) model with MSPE (calculated from equation 4). Over all breed groups, the predicted DMI was within five percent of the observed DMI 49% of the time and 71% of predictions were within 10% of observed values. This is consistent with the NRC (2001) results where a validation set was used to test the model. In that test, the RMSPE was 1.75 kg/d with a bias of -0.16 kg/d in primiparous cows. The RMSPE is also consistent with findings by Ellis et al. (2006) and Shah and Murphy (2006), but the mean bias had an opposite sign and was lower than the 0.95 kg/d reported by Shah and Murphy (2006).

Figure 4.1 shows the distribution of residuals for DMI predictions using the NRC (2001) model. It shows a tendency for over-prediction of intakes for JJ, HJ, and JH and an under-prediction for HH. The MSPE, RMSPE, and mean bias for each breed group are located in Table 4.4. The residuals for DMI were analyzed using the PROC GLM procedure of SAS (SAS, 2004). The HH and HJ breed groups were statistically different ( $P < 0.05$ ) indicating that the HH had a higher error of prediction than the HJ using the NRC (2001) model. In addition, the mean bias was positive for the HH breed group indicating a slight underestimation of DMI, and was negative for HJ, JH, and JJ which indicated a slight overestimation of DMI. Additionally, the HJ and JH breed groups had a lower MSPE than the HH breed group and the JJ breed group had the lowest MSPE.

The use of FCM instead of ECM in the model could have been one reason for the differences in the residuals of predicted DMI. The USDA-AIPL (2007) reported that the protein percent was 3.01% for Holsteins and 3.57% for Jerseys in the national standardized lactation records used in genetic evaluations. In addition to breed differences in protein percent, heterosis affects protein with a 4.1% heterosis value being reported for protein yield (VanRaden and Sanders, 2003). There should be some adjustment for protein content in calculating the energy in milk if different breeds are used. Another possible explanation of the differences could be due to the differences in growth rates. The data were from first lactation animals and there could have been differences in the growth rates and maturity between the breeds, which would have impacted the amount of energy allocated to growth and would have altered DMI causing the slower maturing breeds to consume more DMI than predicted.

The under-predictions of intake have economic implications within a decision support model. Feed costs would be under-predicted and profitability would be overestimated (Fuentes-Pila et al., 1996) for HH, particularly relative to the other three groups where intake was over-predicted. Potentially the HJ, JH, and JJ would not appear to be as profitable if DMI predictions were used in this fashion for a decision support model.

Table 4.5 shows the results of regressing residuals on variables in NRC (2001) model. Breed group was significant, which was expected (see previous paragraph). There was a significant relationship with residuals for DMI and FCM. Residuals are plotted against FCM for the different breed groups in Figure 4.2. The graphs show over-predictions of DMI when FCM is high (regardless of breed). A possible explanation was that cows were mobilizing body energy at high levels of FCM in order to meet the added energy demands, rather than actually consuming feed. Milk production in dairy cattle has increased since the NRC (2001) model was developed. There may be need to adjust the model for higher producing cows.

#### *4.4.2 The Prediction Equations*

Table 4.6 contains Pearson correlation coefficients for all variables collected. The highly correlated coefficients (above 0.70) were BW with MBW, height with BW and

MBW, additive Holstein genes with height, DPREG with DIM, AVT with MINT, AVT with MAXT, and MINT with MAXT. The temperature variables were extremely highly correlated (above 0.90). Resulting multicollinearity problems led to use of only one temperature variable in prediction equations. The temperature variable chosen was MINT as it produced a higher  $R^2$  relative to other temperature variables. This finding is consistent with Roseler et al. (1997b), who found that daytime heat stress had less effect on DMI when there was a temporary nighttime reprieve. Holter et al. (1996) also found a higher correlation between minimum temperature and DMI than the other temperature variables.

Final regression variables accounted for 41% to 49% of the variability in feed intakes with RMSPE ranging from 1.8 kg/d to 2.5 kg/d. These results are comparable to Roseler et al, 1997a, and NRC, 2001 but had a lower coefficient of determination than others (Holter et al., 1996; Ellis et al., 2006; and Shah and Murphy, 2006). Regression coefficients for the two equations using all breeds (equation A and B) are in Table 4.7, and for individual breed equations (equations C, D, and E) are in Table 4.8.

Height, maternal effects, MAXT, AVT, and BW were excluded from all models. The temperature variables and BW were highly correlated with other terms (minimum temperature and MBW). Height and maternal effects were not significant.

Table 4.7 shows the regression coefficients for equations A and B. Differences between the all breed equation (A) and all breed equation (B) were due to the partitioning of breed. The effect of breed was significant in equation A; HH had a larger adjustment for DMI than the HJ and JJ but was not different from JH ( $P < 0.05$ ). The HJ and JH breed groups were not significantly different from each other. The JJ required a lower adjustment than all the other breed groups. The all-breed group equation based on percent Holstein genes in the animal and heterosis level (equation B) showed significant additive effects of Holstein genes. Purebred Holstein cows were expected to consume 0.85 kg more per day than purebred Jerseys. Significant heterosis effects indicate that HJ and JH groups consumed 0.22 kg per day more after accounting for the additive effects of Holstein and Jersey genes and other variables in the equation. Equations A and B were very similar for all of the other coefficients in the model, as was expected.

The effects for AAC, MINT, and DIM on the prediction of DMI (holding all other variables in equation A constant) are located in Figure 4.3, 4.4, and 4.5. Cows older at calving consumed up to 1 kg more than cows that calved at younger ages. Dry matter intake increased rapidly with day in milk at the beginning of lactation, plateaued, decreased slightly and then increased at the tail end of lactation. Pregnancy could have affected the last part of lactation and caused the final increase in DMI. Cows ate more when MINT was intermediate. The decreased intakes at the lower end of MINT was surprising. However, the lowest temperatures were all during the same trial period, trial was not fit in the model, so it could be a trial effect that caused the decreased DMI at the lowest MINT.

Table 4.8 shows the regression coefficients for the individual breed models. HJ and JH breed groups were not different from each other in model A and maternal effects were not significant so only one model was used for crossbreds (equation D).

Variables that were included in all models A-E were DPREG, ECM and the linear, quadratic and cubic form for DIM. There were differences in other variables included among the different equations. Body condition score was not a significant predictor for the all breed or crossbred equations so it was removed, but was a significant predictor for both Holstein and Jersey equations. Metabolic body weight was useful in all equations except for Jersey, perhaps due to the importance of BCS in Jerseys. Body condition scores could have accounted for enough of the difference in body weight among the Jerseys to replace MBW in the model. Effects of AAC and AAC\*AAC were significant in both purebred Holsteins and crossbreds. However, AAC was not significant in the Jersey breed. The range for AAC in the JJ was 200 days versus 242, 306, and 334 days for the JH, HJ, and HH, respectively. Dry matter intake was not significantly affected by MINT in Jerseys. This finding is in contrast to Holter et al. (1996) where MINT was significant for Jerseys, but the data used in that experiment were from Georgia and the cows were exposed to higher temperatures than the cows in our experiment. Additionally, Roseler et al. (1997b) found that depression of DMI associated with heat stress was lower for first lactation than for multiparous cows.

The prediction equations developed in this paper can not be statistically compared to the NRC (2001) equation using the data set in this paper, because the entire data set

was used to derive the equations (A-E). For example, there was a mean bias in the NRC (2001) equations, however, models developed in this study cannot have a mean bias because the residuals sum to zero. The data in this paper were confounded with the development of our prediction equations. However, the RMSPE for the breed groups using the models developed in this paper were lower than the RMSPE from the same data using the NRC (2001) model. A validation data set based on data that were not used in the model building process would be required to compare our models with the NRC (2001) model.

#### **4.5 CONCLUSIONS**

This study provided evidence that the breed groups differ in DMI predictions, even after accounting for standard variables in the model. Body weight and milk production are two main factors in DMI predictions. After consideration of those factors, one might expect there to be no differences for DMI for breeds, however, this was not the case. There were differences between the breed groups in both the NRC (2001) model and breed DMI equations developed in the study. This is important because current models should not just be scaled to body size and milk production to account for breed differences. The crossbreeding population has been increasing in the U.S. over the last ten years. This could be a problem for nutritionist who develop rations for non-Holstein herds. Evidence suggests an adjustment or possibly a separate prediction equation for the different breeds. Further research with larger data sets is needed to refine models across breed and lactations or to have a validation data set to test the models.



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**Table 4.1. Description of potential variables (O = observed, C = calculated) to predict dry matter intake of first lactation Holstein, Jerseys, and reciprocal crosses**

Variable	Variable Type	Description
AAC	O	Age at calving in first lactation in days
BCS	O	Body condition scores taken every five weeks
BW	C	Weekly body weight averaged from daily body weights
MBW	C	Weekly metabolic body weight averaged from daily body weight
Height	O	Hip heights taken every 5 weeks
DPREG	O	Days pregnant calculated by date of feed intake observation minus conception date
ECM	C	Energy-corrected milk calculated from daily milk and monthly fat and protein percent
Breed	O	Breed group effects
Additive	O	Percent Holstein genes in the cow
Maternal	O	Percent Holstein genes in the dam of the cow
Heterosis	O	Percent heterosis in the cow
MINT	O	Daily minimum temperature recorded by Blacksburg National Weather Service
MAXT	O	Daily maximum temperature recorded by Blacksburg National Weather Service
AVT	O	Daily average temperature recorded by Blacksburg National Weather Service

**Table 4.2. Means and ranges by breed group for prospective variables in dry matter intake prediction equations**

Variable	HH <sup>1</sup>		HJ		JH		JJ	
	$\bar{x}$	range	$\bar{x}$	range	$\bar{x}$	range	$\bar{x}$	range
DMI (kg/d)	21.5	3.3-33.7	20.6	3.1-31.2	20.3	3.4-31.5	17.3	4.7-22.8
AAC <sup>2</sup> (d)	755	628-962	714	587-893	720	624-866	762	684-884
DIM (d)	148	10-305	167	13-305	167	14-305	162	15-305
BCS	2.84	1.75-4.25	2.82	1.00-4.00	2.63	1.50-3.75	2.88	2.00-3.75
BW (kg)	550	441-777	519	394-682	498	369-598	412	352-510
MBW (kg)	166	96-147	109	88-133	105	84-121	92	81-107
Height (cm)	146	138-156	139	132-146	139	130-149	128	121-144
DPREG <sup>3</sup> (d)	43	0-226	60	0-232	66	0-231	68	0-217
ECM (kg)	32.0	7.2-62.9	31.5	5.2-57.4	31.3	7.5-50.9	26.7	14.8-47.9
MINT <sup>4</sup>	5.0	-14.4-21.7	5.4	-14.4-21.7	4.5	-14.4-21.7	6.4	-10.0-21.7
MAXT <sup>5</sup>	18.1	-3.9-35.6	18.3	-3.9-35.6	17.3	-3.9-35.6	19.8	-2.8-35.6
AVET <sup>6</sup>	11.7	-8.3-27.2	12.0	-8.3-27.2	11.0	-8.3-27.2	13.3	-5.0-27.2

<sup>1</sup> sire breed listed first

<sup>2</sup> AAC = age at calving

<sup>3</sup> DPREG = days pregnant

<sup>4</sup> MINT = minimum temperature in C<sup>o</sup>

<sup>5</sup> MAXT = maximum temperature in C<sup>o</sup>

<sup>6</sup> AVET = average temperature in C<sup>o</sup>

**Table 4.3. Coefficients for additive Holstein genes, maternal Holstein genes, and heterosis in breed groups.**

Breed/Component	HH <sup>1</sup>	HJ	JH	JJ
Additive	1	0.5	0.5	0
Maternal	1	0	1	0
Heterosis	0	1	1	0

<sup>1</sup> sire breed listed first

**Table 4.4. Predicted and observed means, mean square prediction errors, root mean square prediction errors, and mean bias for predictions of dry matter intakes of first lactation animals from Holstein, Jersey, and reciprocal crosses using the NRC (2001) model (equation 3 in the text)**

Breed	Observed (kg/d)	Predicted (kg/d)	MSPE <sup>2</sup> (kg <sup>2</sup> /d)	RMSPE <sup>3</sup> (kg/d)	Mean Bias (kg/d)
HH <sup>1</sup>	21.4	21.4	8.65 <sup>a</sup> ± 0.26	2.94	0.22 <sup>a</sup> ± 0.05
HJ	20.8	20.8	5.77 <sup>b,c</sup> ± 0.32	2.40	-0.20 <sup>b</sup> ± 0.06
JH	20.3	20.3	6.09 <sup>b</sup> ± 0.35	2.47	0.00 <sup>b</sup> ± 0.06
JJ	17.3	17.5	4.18 <sup>c</sup> ± 0.53	2.04	-0.23 <sup>b</sup> ± 0.09

\* different superscripts represent statistical differences ( $P < 0.05$ )

<sup>1</sup> sire breed listed first

<sup>2</sup> MSPE is mean square prediction error

<sup>3</sup> RMSPE is root mean square prediction error



**Table 4.5. Prediction of residuals of DMI (kg/d) from FCM<sup>1</sup>, MBW<sup>2</sup>, and WOL<sup>3</sup> to the using the NRC (2001) model in Holstein, Jersey, and reciprocal crosses**

Variable <sup>4</sup>	Coefficient	P-Value
Intercept	13.83 ± 2.43	< 0.001
FCM	0.32 ± 0.03	<0.001
FCM * FCM	-6.9 x 10 <sup>-3</sup> ± 4.8 x 10 <sup>-4</sup>	<0.001
MBW	0.19 ± 0.04	<0.001
MBW * MBW	-7.0 x 10 <sup>-4</sup> ± 1.9 x 10 <sup>-4</sup>	<0.001
WOL	-0.016 ± -0.013	0.20
WOL * WOL	6.0 x 10 <sup>-4</sup> ± 3.0 x 10 <sup>-4</sup>	0.05

<sup>1</sup> FCM is four percent fat corrected milk

<sup>2</sup> MBW is metabolic body weight

<sup>3</sup> WOL is week of lactation

<sup>4</sup> breed group was also significant

**Table 4.6. Pearson correlation coefficients among potential variables to predict DMI of Holsteins, Jerseys and reciprocal crosses**

Variable	Variable Number													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1. DMI kg/d														
2. AAC <sup>2</sup>	0.24													
3. DIM	0.40	NS <sup>1</sup>												
4. BCS	0.07	NS	0.31											
5. BW	0.40	0.25	0.44	0.40										
6. MBW	0.40	0.24	0.44	0.39	1.00									
7. Height	0.31	0.22	0.05	0.02	0.76	0.76								
8. DPREG <sup>3</sup>	0.05	NS	0.78	0.22	0.34	0.34	0.01							
9. ECM	0.48	0.29	-0.13	-0.23	0.04	0.04	0.13	-0.18						
10. Additive	0.31	0.13	-0.09	0.05	0.66	0.66	0.84	-0.14	0.20					
11. Maternal	0.19	0.11	-0.06	-0.08	0.37	0.37	0.57	-0.07	0.12	0.68				
12. Heterosis	-0.03	-0.24	-0.20	-0.16	-0.21	-0.21	-0.27	0.11	0.04	-0.48	-0.35			
13. MINT <sup>4</sup>	NS	0.08	-0.02	NS	NS	NS	-0.04	NS	NS	NS	-0.05	NS		
14. AVT <sup>5</sup>	NS	0.09	-0.04	NS	NS	NS	-0.03	NS	NS	NS	-0.05	NS	0.98	
15. MAXT <sup>6</sup>	NS	0.10	-0.04	NS	NS	NS	-0.04	NS	NS	NS	-0.05	NS	0.89	0.97

<sup>1</sup>NS = not significant

<sup>2</sup> AAC = age at calving

<sup>2</sup> DPREG = days pregnant

<sup>3</sup> MINT = minimum temperature

<sup>4</sup> AVT = average temperature

<sup>5</sup> MAXT = maximum temperature

**Table 4.7. Regression coefficients for all breed group models for Holstein, Jersey, and reciprocal crosses**

Equation	Regression Coefficients	
	A	B
Intercept	2.9734 ± 2.50	2.8129 ± 2.50
AAC <sup>1</sup>	-0.0203 ± 0.0064	-0.0196 ± 0.0064
AAC*AAC	1.531 x 10 <sup>-5</sup> ± 4.2 x 10 <sup>-6</sup>	1.490 x 10 <sup>-5</sup> ± 4.2 x 10 <sup>-6</sup>
DIM	0.1330 ± 0.0046	0.1332 ± 0.0046
DIM*DIM	-7.023 x 10 <sup>-4</sup> ± 3.2 x 10 <sup>-5</sup>	-7.039 x 10 <sup>-4</sup> ± 3.2 x 10 <sup>-5</sup>
DIM*DIM*DIM	1.154 x 10 <sup>-6</sup> ± 7.0 x 10 <sup>-8</sup>	1.158 x 10 <sup>-6</sup> ± 7.0 x 10 <sup>-8</sup>
DPREG	-3.852 x 10 <sup>-3</sup> ± 6.7 x 10 <sup>-3</sup>	-3.777 x 10 <sup>-3</sup> ± 6.7 x 10 <sup>-3</sup>
ECM	0.2452 ± 5.4 x 10 <sup>-3</sup>	0.2448 ± 5.4 x 10 <sup>-3</sup>
MBW	0.0850 ± 5.3 x 10 <sup>-3</sup>	0.0836 ± 5.3 x 10 <sup>-3</sup>
MINT <sup>3</sup>	0.0257 ± 6.7 x 10 <sup>-3</sup>	0.0256 ± 6.7 x 10 <sup>-3</sup>
MNT*MINT	-7.166 x 10 <sup>-3</sup> ± 7.2 x 10 <sup>-4</sup>	-7.157 x 10 <sup>-3</sup> ± 7.2 x 10 <sup>-4</sup>
MINT*MINT*MINT	1.936 x 10 <sup>-4</sup> ± 4.5 x 10 <sup>-5</sup>	1.928 x 10 <sup>-4</sup> ± 4.5 x 10 <sup>-5</sup>
Breed		
HH <sup>2</sup>	0.8508 <sup>a</sup> ± 0.18	-
HJ	0.5940 <sup>b</sup> ± 0.15	-
JH	0.7070 <sup>a,b</sup> ± 0.14	-
JJ	0 <sup>c</sup>	-
Additive	-	0.8454 ± 0.18
Heterosis	-	0.2237 ± 0.07
Coefficient of Determination	0.4907	0.4906
RMSPE <sup>4</sup>	2.5170	2.5171

\* breeds with different superscripts are statistically different from each other  $P < 0.05$

<sup>1</sup> AAC = age at calving, (d)

<sup>2</sup> breed group is denoted as sire breed by dam breed

<sup>3</sup> MINT = minimum temperature

<sup>4</sup> RMSPE is root mean square prediction error

**Table 4.8. Regression coefficients for individual breed group models in first lactation Holstein, Jersey, and reciprocal crosses**

Breed Group	Regression Coefficients		
	Holstein	Crossbred	Jersey
Equation	C	D	E
Intercept	10.0048 ± 5.05	9.0688 ± 3.32	4.3908 ± 0.85
AAC <sup>1</sup>	-0.0525 ± 0.013	-0.0287 ± 0.009	-
AAC*AAC	3.370 x 10 <sup>-5</sup> ±8.1 x 10 <sup>-6</sup>	2.279 x 10 <sup>-5</sup> ±5.0 x 10 <sup>-6</sup>	-
DIM	0.1528 ± 0.008	0.1068 ± 0.006	0.1078 ± 0.01
DIM *DIM	-8.642 x 10 <sup>-4</sup> ±5.7 x 10 <sup>-5</sup>	-5.223 x 10 <sup>-4</sup> ±4.3 x 10 <sup>-5</sup>	-5.198 x 10 <sup>-4</sup> ±8.0 x 10 <sup>-5</sup>
DIM*DIM*DIM	1.420 x 10 <sup>-6</sup> ±1.4 x 10 <sup>-6</sup>	8.080 x 10 <sup>-7</sup> ±9.0 x 10 <sup>-8</sup>	8.490 x 10 <sup>-7</sup> ±1.6 x 10 <sup>-7</sup>
BCS	0.2812 ± 0.14	-	0.4832 ± 0.19
DPREG <sup>2</sup>	-8.642 x 10 <sup>-3</sup> ± 0.002	-2.470 x 10 <sup>-3</sup> ±8.0 x 10 <sup>-4</sup>	-0.0112 ± 0.002
ECM	0.2626 ± 0.010	0.2292 ± 0.007	0.2042 ± 0.017
MBW	0.1345 ± 0.01	0.0660 ± 0.006	-
MINT <sup>3</sup>	0.0349 ± 0.012	0.0212 ± 0.009	-
MINT*MINT	-7.762 x 10 <sup>-3</sup> ±1.2 x 10 <sup>-3</sup>	-6.704 x 10 <sup>-3</sup> ±8.8 x 10 <sup>-4</sup>	-
MINT*MINT* MINT	1.561 x 10 <sup>-4</sup> ±8.0 x 10 <sup>-5</sup>	2.112 x 10 <sup>-4</sup> ±5.5 x 10 <sup>-5</sup>	-
Coefficient of Determination	0.4390	0.4389	0.401
RMSPE <sup>4</sup>	2.285	2.285	1.800

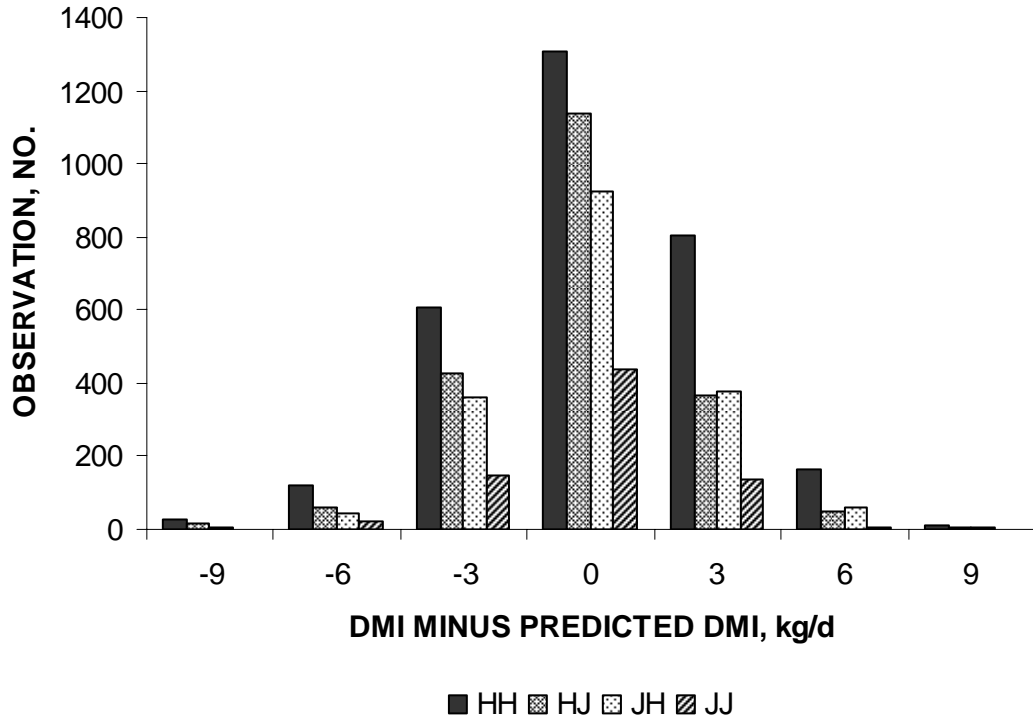
<sup>1</sup>ACC = age at calving (d)

<sup>2</sup>DPREG = days pregnant

<sup>3</sup>MINT = minimum daily temperature

<sup>4</sup>RMSPE = root means square prediction error

**Figure 4.1.** Frequency distribution of differences between observed and predicted DMI of first lactation HH, HJ, JH, and JJ breed groups (sire breed listed first) using NRC (2001) DMI equation.



**Figure 4.2.** Relationship between residual (observed minus predicted) and fat corrected milk (FCM) for DMI for the four different breed groups HH-purebred Holstein, HJ – Holstein sire out of Jersey dam, JH – Jersey sired out of Holstein dam, and JJ – purebred Jersey using the NRC (2001) model.

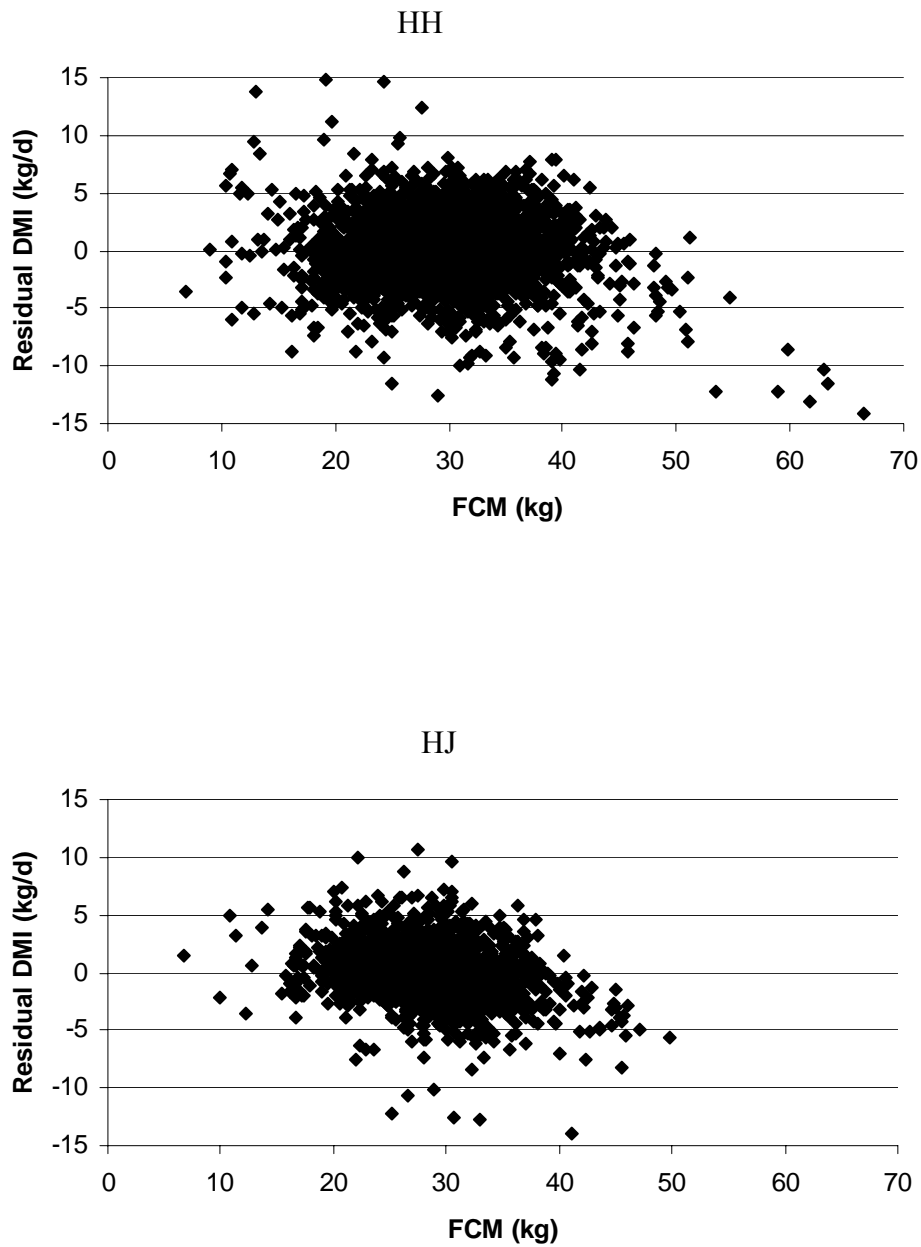
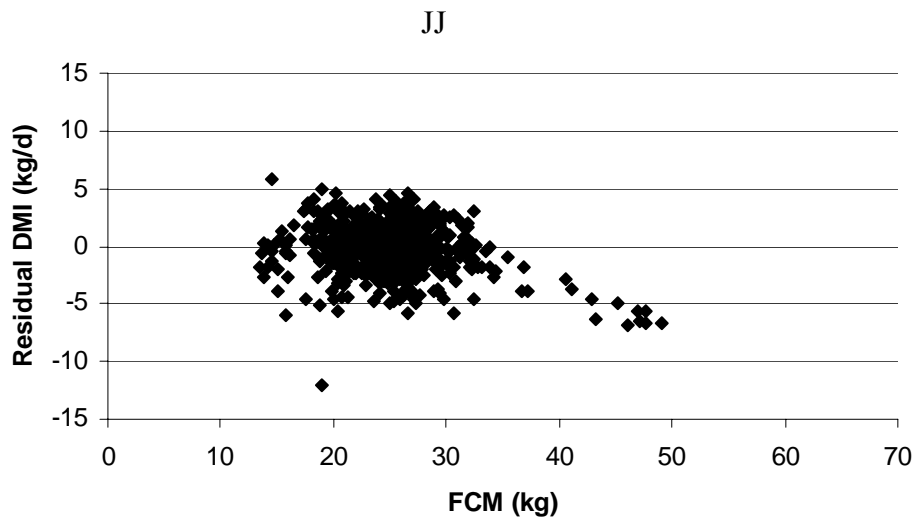
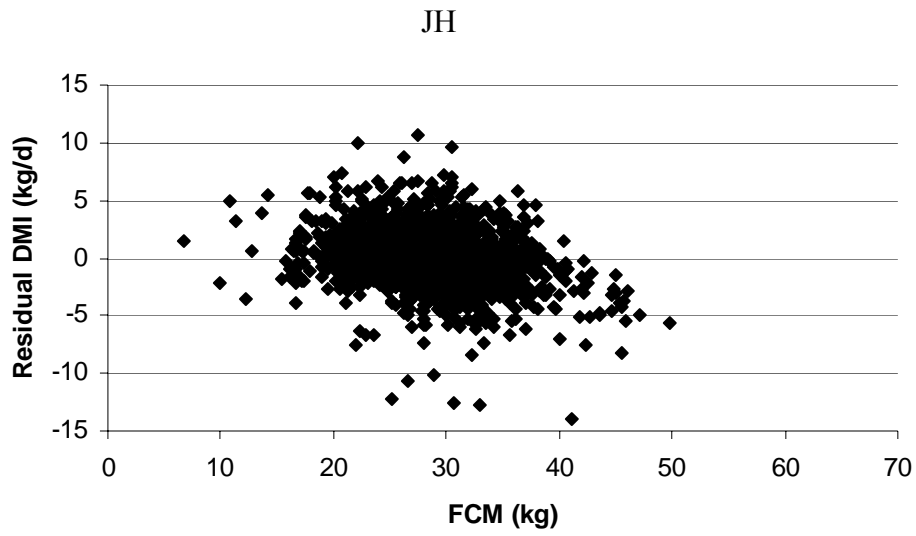
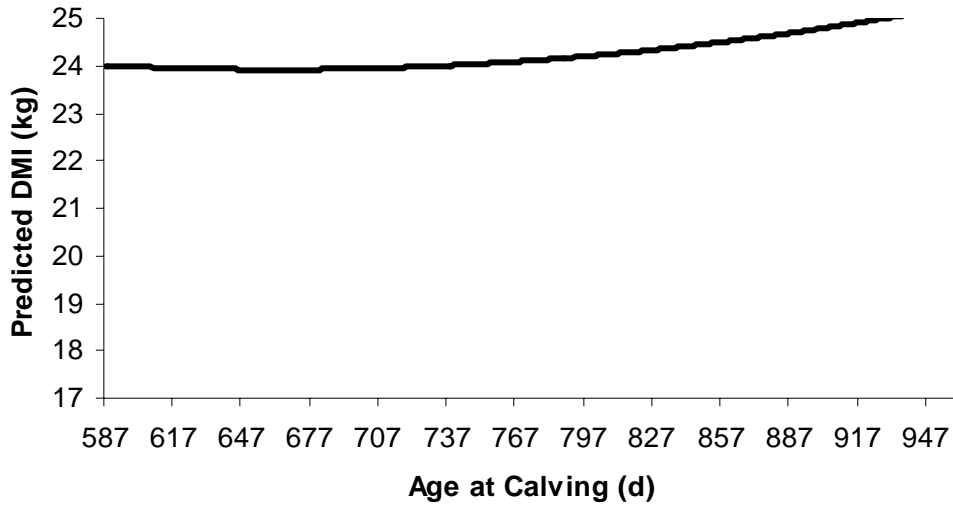


Figure 4.2. Continued

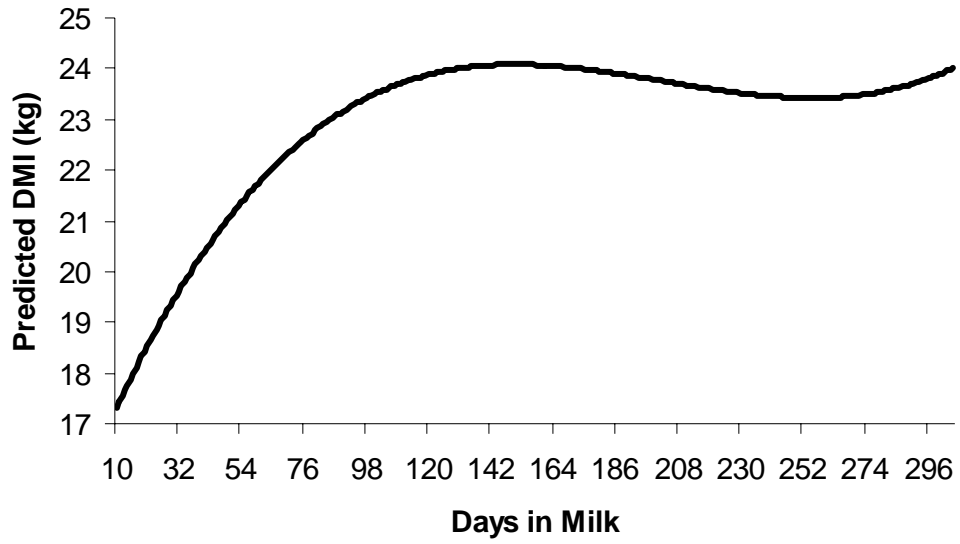




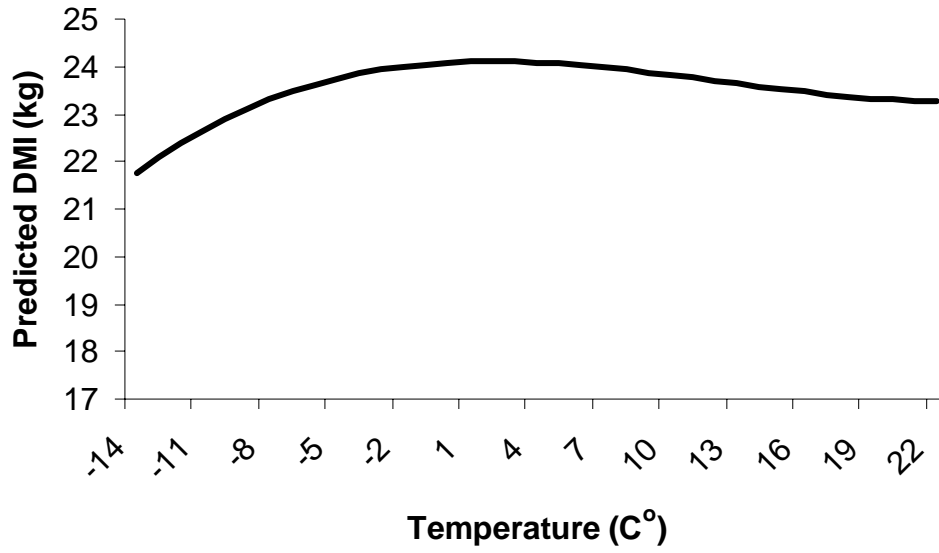
**Figure 4.3.** Graph of effect of age at calving on predicted dry matter intake (DMI) holding all other variables constant (relative to Holstein averages) using model A.



**Figure 4.4.** Graph of days in milk effect on predicted dry matter intake (DMI) holding all other variables constant (relative to Holstein averages) using model A.



**Figure 4.5.** Graph of minimum daily temperature effect on predicted dry matter intake (DMI) holding all other variables constant (relative to Holstein averages) using model A.



## CHAPTER 5

### **Energy Balance in First Lactation Holsteins, Jerseys, and Reciprocal Crosses Estimated Using Random Regression**

#### **5.1 ABSTRACT**

The Virginia Tech crossbreeding project began in the fall of 2002 by mating Holstein and Jersey foundation females to four Holstein and four Jersey bulls to create HH, HJ, JH, and JJ breed groups with sire breed listed first. Collection of individual daily feed intakes began in September 2005 and continued through March 2008. Intakes were measured for two weeks out of every six week period on cows in first lactation and less than 306 days in milk on 44, 32, 29, and 13 HH, HJ, JH, and JJ, respectively. The ration was analyzed for nutrient content and  $NE_L$  (Mcal/kg) was predicted from the nutrient analyses. Body weights and milk weights were collected daily with milk components measured monthly.  $NE_L$  requirement for maintenance, growth (in the form of retained energy), and pregnancy were calculated using NRC (2001) equations. Random regression models were used to determine consumed  $NE_L$  and  $NE_L$  required for production, maintenance, and body weight at every week in lactation (WOL). Energy required for growth was calculated for each cow at each stage of lactation using five two month stages. Energy balance was estimated by subtracting the energy required for production, maintenance, growth, and pregnancy from the  $NE_L$  consumed. A linear model with fixed effects of breed group, year-season of freshening group, and a linear and quadratic effect of age at calving was used to analyze the energy terms. HJ and JH breed groups were not different in any of the analyses for energy terms. The HH cows consumed more energy than HJ and JJ cows. There were no differences for total energy for pregnancy. The HH, HJ, and JH were not different from each other for energy required for production but they required more energy for production than the JJ. No differences were found for percent energy used for pregnancy and growth. The JH

allocated less energy to maintenance than the HH (25.8% to 27.6%). Breed group explained significant variation ( $P < 0.10$ ) for percent of energy partitioned to production, but breed groups were not different from each other when using multiple comparison adjustments. There were no differences for week to return to positive energy balance, return to positive cumulative energy balance or energy balance at week 21 of lactation. Breed group explained significant variation for cumulative energy balance at the end of lactation ( $P < 0.10$ ), but no pair of breed groups differed significantly. There was evidence of breed group differences in characterization of energy balance that warrants further study.

Key words (crossbreeding, dairy cows, energy balance)

## 5.2 INTRODUCTION

Energy balance (EB) in dairy cattle is of increasing importance because selection for higher milk production has increased use of body reserves in early lactation (Coffey et al., 2001; Konen et al., 2001). Heavier reliance on body reserves in early lactation has a negative impact on fertility and health (Hansen, 2000; Banos et al., 2006). Energy balance is the difference in energy a dairy animal consumes in feed and usage of the energy for growth, maintenance, milk production, and reproduction. When there is a negative EB, stored body fat and tissue is mobilized to meet the extra needs. Since activity is not explicitly considered in this calculation, reduced activity could spare some energy minimizing the apparent energy deficit. High producing dairy cows do not usually eat enough in early lactation to maintain a positive EB. Extended periods of negative EB can lead to health problems, poor reproductive performance, reduced production, and may lead to early culling or death. Higher yields exacerbate the problem.

Several studies have investigated EB across lactations (Coffey et al., 2002; Banos et al., 2005; Friggens et al., 2007) and EB and the relationships to health and fertility traits (De Vries et al., 2000; Banos et al., 2006). Few studies have compared energy balance across genetic lines (Coffey et al., 2004; Friggens et al., 2007). Coffey et al. (2004) found that cows selected for high productivity were predisposed to use body energy reserves to support production. Friggens et al. (2007) found significant

differences in energy balance between the Danish Holstein, Danish Red, and Jersey. The study also found an interaction of breed by parity in the first half of lactation. This was because the Jerseys mobilized more energy in the first half of first lactation based on observations in other breeds. There are genetic influences on EB, however, current literature contains no EB studies including crossbred cows.

Crossbreeding is of current interest in the dairy industry, and the number of crossbreds has increased in the U.S. for the last ten years (VanRaden and Sanders, 2003). Crossbreeding has been shown to improve milk components, fertility, and productive life (VanRaden and Sanders, 2003; Anderson et al., 2007; Heins et al., 2008a,b). There have been a few studies on crossbreeding and feed efficiency, but they have produced mixed results. Heins et al. (2008b) and Wang et al. (1992) found that the crossbreds did not differ from purebred Holsteins, whereas, Schwager-Suter et al., 2001 found crossbreds to have a greater feed efficiency. There may be advantages for crossbreds in energy balance (e.g. shorter return to positive energy balance). The objectives of this work were to compare purebred Holsteins, Jerseys, and reciprocal crosses for differences in EB and components of EB under a single management system.

## **5.3 MATERIALS AND METHODS**

### *5.3.1 Experimental Design*

The crossbreeding project at Virginia Tech began in the fall of 2002. The study was designed as a classical diallel scheme having Holstein and Jersey foundation females mated to four Holstein bulls and four Jersey bulls to create JJ, HH, JH, and HJ breed groups with sire breed listed first. The foundation females were mated using heterospermic semen that consisted of a mix of one Holstein sire paired with one Jersey sire as explained by Kasimanickam et al. (2006). The first heifers from the project were born in June 2003 and calved between June 2005 and February 2008. The study included 118 cows including 44, 32, 29, and 13 HH, HJ, JH, and JJ, respectively. There were fewer Jerseys due to poor results from the Jersey bulls in the heterospermic trial (Kasimanickam et al., 2006).

### 5.3.2 Data

Data collected contained daily dry matter intake (DMI) observations from first lactation Holsteins, Jerseys, and reciprocal crosses at the Virginia Tech dairy. Individual daily feed intakes were measured in two week time intervals out of every six week period (two weeks on, four weeks off) using the Calan<sup>TM</sup> door system (American Calan, Northwood, NH). Cows were fed the same total mixed ration ad libitum once a day. Feed offered to individual cows was weighed on one day, and refusals were weighed the following day. Feed offered was adjusted over time so that refusal rates were approximately 10% of the feed a cow was offered. Forages, grains, and concentrates were submitted for nutrient analyses at least once during each trial period. An “as-fed” intake was collected during the feed intake cycle and DMI was calculated from nutrient analyses and as-fed intake. Net energy for lactation  $NE_L$  (Mcal) concentration in the feed was calculated for each trial period using the ration and information from the feed analysis.

Intakes began in September 2005 and continued through March 2008. Each intake trial included approximately 30 cows, but ranged from 8 cows in September 2005 to 48 cows in July 2007. All cows were housed in a single pen during the trial period, regardless of breed group. Cows were required to be over two weeks in milk to be included in a trial and were returned for subsequent trial periods until completion of 305 days in milk (DIM). A total of 26 trials were conducted including four trials from other nutrition feeding trials where intakes were unrestricted by ration or feed offered. Final data included 9,971 unedited daily observations of feed intakes. Daily feed intake observations per cow ranged from 12 to 223 with the average cow having 83 unedited feed intake observations.

Daily intakes in terms of  $NE_L$  consumed were edited for equipment malfunctions, adaptation time to the Calan doors, and removal of cows that became noticeably sick during the trial, decreasing data from 9,971 to 8,151 observations. Intakes of  $NE_L$  consumed were further edited by calculating a confidence interval for each cow within each trial. Intakes that fell four standard deviations (SD) outside of the mean were discarded. This restriction reduced the data by 1.3% to 8,042 daily intakes on 118 cows.

Intakes were then averaged over week of lactation (WOL). There were 619, 470, 399, and 179 weekly observations on HH, HJ, JH, and JJ.

Body weights (BW) and milk weights were recorded twice daily by the Afifarm™ herd management software (S.A.E. Afikim, Kibbutz Afikim, Israel). Body weights were measured as the cow left the milking parlor. Body weights and milk weights were used from 18 to 305 DIM. A weekly average BW was used to account for large variation within daily BW.

Milk weights were edited by partitioning the lactation into five stages of sixty days each and a mean and SD were determined within breed group within stage. Originally, records that were three SD outside of the mean for breed group within stage were discarded, however, using this method five cows lost more than 20 records and 280 total records were discarded. However, the edit restriction confidence interval was increased to four SD and no cow lost more than eight records in her lactation. A total of 32,090 edited records on daily milk weights were available, including 11,411, 9,092, 7,978, and 3,609 records for HH, HJ, JH, and JJ, respectively. Discarded records included 24, 7, 18, and 11 for HH, HJ, JH, and JJ which were less than one percent for all breed groups.

DHI record tests were performed monthly and provided estimates of milk fat percent and protein percent. Milk components and daily milk weights were then combined using the test day method as explained by Wiggans and Goddard (1997). Milk and components were then averaged over WOL. Daily milk weights were converted to 1,615, 1,263, 1,109, and 503 weekly means for HH, HJ, JH, and JJ. Body condition scores (BCS) were assigned using the 5 point system starting from 0 (thin) to 5 (fat) with increments of 0.25 as described by Wildman et al. (1982). Cows were assigned BCS every five weeks from calving until 305 days in lactation by a single evaluator. Table 5.1 shows the means and ranges for the different breed groups for the different variables and is based on records calculated for individual days in milk.

Pregnancy was defined as confirmed pregnant by a veterinarian and, were applicable, followed by subsequent calving. Days carried calf was calculated as date of breeding minus the date of the observation. There were three year-season of freshening groups per year (9 year-season groups). A one-generation pedigree was used for all



animals in the project and consisted of animal, sire, and dam. A more detailed description of the sires in the project can be found in Chapter 3. Stage of lactation was defined as five two-month periods from week 3 in lactation through week 43 of lactation.

Net energy for lactation (NE<sub>L</sub> (Mcal)) was calculated on a per day basis for maintenance, milk production, retained energy, and pregnancy using the weekly averages. NE<sub>L</sub> followed NRC (2001) as shown in Appendix A. Retained energy (RE) was used for the estimate of growth requirement using body weight and average daily gain. The NRC (2001) does not account for energy requirements for pregnancy until the 190<sup>th</sup> day in gestation. Therefore, estimates of energy requirements for pregnancy do not begin until 190 days carried calf as shown in Appendix A. Table 5.2 shows the assumptions used for each breed group in NRC (2001) models for retained energy, and pregnancy requirements. Crossbred mature body weight was calculated from the mid parent average plus 5.6% heterosis on mature body weight. Calf birth weight was estimated in the same manner and the calculation can be found in Appendix A.

#### 5.3.4 Calculations of Energy Balance

A random regression model using orthogonal polynomials (Schaeffer, 2003) was used to estimate separate curves for each cow for NE<sub>L</sub> consumed, NE<sub>L</sub> used for milk production, NE<sub>L</sub> needed for maintenance, and BW. A full animal model with a one generation pedigree was used. The random regression models using fixed and random effects were estimated using ASREML software (Gilmour et al., 2006). The random regression model was:

$$Y_{ijlqm} = GS_i + YS_j + \beta_1 age + \beta_2 (age)^2 + \sum_m^{f-1} b_m P_m W_q + \sum_m^{k-1} a_{lm} P_m W_q + PE_l + e_{ijlqm} \quad [1]$$

where  $Y_{ijlqm}$  was the observation (NE<sub>L</sub> consumed, or NE<sub>L</sub> for milk production, or NE<sub>L</sub> for maintenance, or BW);  $GS_i$  was the fixed effect of breed group by stage of lactation  $i$ ;  $YS$  was the fixed effect of year-season of freshening  $j$ ;  $\beta_1$  and  $\beta_2$  were the linear and quadratic coefficients on age at calving;  $W_q$  was the week  $q$  of lactation;  $P_m$  was the  $m^{\text{th}}$  orthogonal polynomial of week  $q$ ;  $b_m$  the fixed regression coefficient associated with the overall curve for the  $m^{\text{th}}$  orthogonal polynomial;  $a_{lm}$  was the random regression coefficient associated with animal  $l$  for the  $m^{\text{th}}$  orthogonal polynomial;  $PE_l$  was the

random permanent environment associated with animal  $l$ ; and  $e_{ijklm}$  was the random residual effect. The parameters  $f$  and  $k$  are the order of the fixed and random polynomials, respectively. The models for  $NE_L$  for production, and  $NE_L$  consumed used polynomials to the third order for both the random and fixed effects. The models for  $NE_L$  for maintenance and BW used polynomials to the second order for fixed, and third order for random effects.

A total of five residual error classes were fit from weeks 3 to 43 of lactation. The residual classes were defined as stage of lactation and partitioned as weeks 3 to 9, 10 to 18, 19 to 27, 28 to 35, and greater than 35. The residual variances were estimated per residual class with the variance within each class being homogenous and the covariance between classes assumed to be zero.

Body condition scores are useful for predictions of lipid and protein mobilization. The covariance between adjacent BCS was high and convergence was not achieved using random regression models for BCS. Accordingly, our definition of energy balance does not include a term for the mobilization of body lipid loss. Body condition score was analyzed by stage of lactation to investigate possible differences in lipid mobilization between the breed groups. This analysis used the PROC MIXED procedure of SAS (SAS Institute, 2004) with a random effect of cow and fixed effects of breed group, stage, breed group by stage interaction, year-season of freshening and a linear and quadratic effect of age at calving.

Energy for growth was defined as the energy used for RE and was calculated using the predictions from the random regression analysis of BW. Attempts to estimate RE by random regression failed as the model did not converge. In a second attempt, RE was calculated weekly using random regression solutions for body weight, but the weekly RE estimates were highly variable. Ultimately, RE was calculated from BW predictions by stage of lactation using the residual classes defined above for each animal. The RE was calculated from the first BW in stage 1 estimated from random regression and using the average between the last BW in the stage and the first BW in the next stage and that BW was used as the first BW in the next stage. The RE for stage of lactation for each cow was then used for the weekly EB calculations.

The animal solutions that were obtained from the random regression analyses were then used to calculate weekly average phenotypic values for all animals in the data set at all WOL (weeks 3 to 43). Energy balance was calculated using the predictions of consumed energy minus the predictions for energy required for maintenance and production (from random regression models), RE, and pregnancy requirements by WOL. Total energy consumed (TEC), total energy required for production (TEP), Total energy required for maintenance (TEM), total energy for growth (TEG), total energy required for pregnancy (TEPR), and overall total cumulative energy balance (TEB) across the lactation were calculated as the sum of the weekly averages multiplied by seven. Ratios of energy required for maintenance, growth, pregnancy, and production to energy consumed were calculated (e.g. TEP/TEC). Return to positive balance within week (PEBW) was defined as the first week where EB was positive. A return to overall positive EB (WPEB) was defined as the first week where the cumulative EB calculation became positive. A cumulative energy balance at week 21 was calculated (TEB<sub>21</sub>) to investigate EB at the stage of lactation where producers would like the cows to be pregnant.

The GLM procedure of SAS (SAS Institute, 2004) was used for the statistical analyses of PEBW, WPEB, TEB<sub>21</sub>, TEB, TEC, TEP, TEPR, TEG, TEM, and the ratios for each of the energy terms. The model was defined as:

$$Y_{ijk} = \mu + G_i + YS_j + \beta_1 \text{age} + \beta_2 (\text{age})^2 + e_{ijk} \quad [2]$$

where  $G_i$  is the  $i^{\text{th}}$  breed group;  $YS_j$  is the  $j^{\text{th}}$  year season of freshening;  $\beta_1$  and  $\beta_2$  are linear and quadratic regression coefficients for age at calving; and  $e_{ijk}$  is the random residual for the  $k^{\text{th}}$  cow in the  $i^{\text{th}}$  breed group from the  $j^{\text{th}}$  year-season of freshening. A Tukey adjustment for least square means for breed groups was used to account for simultaneous comparisons across breed groups. Heterosis was calculated as the percent deviation from the mid parent average.

## 5.4 RESULTS AND DISCUSSION

### 5.4.1 Components of Energy Balance

Table 5.3 includes least square means of TEC, TEP, TEM, TEG, and TEPR for each breed group. The reciprocal cross breed groups (HJ and JH) were not different from

one another in any of the analyses for energy terms, suggesting breed maternal effects were not significant. There were breed group differences for TEC. The HH consumed more energy ( $P < 0.10$ ) than the HJ and JJ breed groups, but were not different from the JH. The JJ consumed the least amount of energy. Breed group differences for TEM were significant. The HH required more energy for maintenance than all the other breed groups and the crosses (HJ and JH) required more energy than the JJ. The HH required more energy for growth than the JH and JJ groups but was not different from the HJ. The HJ, JH, and JJ were not different from each other for TEG. There were no statistical differences between any of the breed groups for TEPR. TEG and TEPR were small in comparison to the other components of energy balance. The HH, HJ, and JH were not different from each other for TEP but required more energy for milk production than the JJ group.

One of the main questions with crossbreeding is how big the crossbreds are in comparison to the purebreds. Jerseys are known to be smaller in size and earlier maturing than the Holstein, but there is little in the literature on the heterosis level of crossing a Jersey with a Holstein for size and growth rate in cows. In our study, the heterosis for TEM was 3.78%. This is an unfavorable heterosis value in that the F1 crossbred is expected to have a 3.78% more energy required for maintenance than that required for the mid parent average. The 3.78% heterosis for maintenance agrees with 3.4 – 3.5% heterosis reported for BW in first lactation (McDowell et al., 1969; Robinson et al., 1980). The heterosis value for TEP was 11.70% which was higher than 6.2% heterosis for milk and 7.2% for fat found by Ahlborn-Brier and Hohenboken (1991) and quite a bit higher than the 3.4%, 4.4% and 4.1% for milk, fat, and protein reported by VanRaden and Sanders (2003). The heterosis value for TEP encompasses heterosis on milk, fat, and protein which all increase milk energy. The heterosis for TEG was 2.21% in an unfavorable direction meaning that the crossbreds required 2.21% more energy for growth than the mid parent average. Heterosis for feed consumed was 8.47%, which was lower than the heterosis for production.

The TEP was converted to energy-constant milk based on 4% fat and 3.2% protein corrected basis. Estimates for total yield from day 18 to day 305 were 8,071 kg, 8,257 kg, 8,274 kg, and 6,727 kg for HH, HJ, JH, and JJ, respectively. The HH, HJ, and

JH were not statistically different from each other in TEP so their production was not different from each other, but were statistically different from JJ. These estimates are 18 days shorter than a typical 305d lactation. Additionally, the numbers may seem lower than the typical HH would produce, but correcting to a 4% fat and a 3.2% protein basis is higher component percentage than that of a typical HH.

The cost of  $NE_L$  (Mcal) has been estimated to be \$0.17 (St-Pierre, 2008). Given this estimate, maintenance costs would be \$455.26, \$424.51, \$412.91, and \$351.65 for HH, HJ, JH, and JJ, respectively. Feed costs for growth would be \$92.85, \$85.07, \$66.64 and \$55.50 for HH, HJ, JH, and JJ. Production costs would be \$1,020.51, \$1,043.97, \$1,046.18, and \$850.60 for HH, HJ, JH and JJ respectively. Pregnancy costs would be \$5.61, \$6.63, \$6.97, and \$4.70 for HH, HJ, JH, and JJ.

#### 5.4.2 Energy Allocation

Table 5.4 shows proportion of energy consumed used for growth, maintenance, pregnancy, and production. There were no statistical differences between the breed groups for percent of energy used for pregnancy and growth, the two smallest partitions of energy use studied. Breed group had a  $P$ -value of 0.086 for production, however, when using a Tukey adjustment for multiple comparisons for the least square means there were no breed groups that were statistically different from another breed group. The trend was that the HJ, JH, and JJ allocated a higher percentage of energy to production than the HH (65.6%, 65.4%, and 66.1% versus 61.9%). There were however, statistical differences in the percent of energy allocated to maintenance. The JH allocated less energy to maintenance than the HH (25.8% to 27.6%). There were no differences between the JH, HJ, and JJ groups and the HH, HJ, and JJ groups for allocation of energy into maintenance. No other variables were significant in the analyses of proportion of energy used for growth, maintenance, pregnancy, and production ( $P < 0.05$ ).

Proportion of energy used for milk production can be a measure of feed efficiency. In feed efficiency terms, defined in our study as energy required for milk/energy consumed, these results agree with Heins et al., (2008b) in which the J x H cross was not different from the pure Holstein for feed efficiency which was defined as energy corrected milk/ dry matter intake. Schwager-Suter et al. (2001) found that J x H

crosses had a higher feed efficiency, defined as energy content in milk/ net energy intake, than the pure Holstein cow. Our results trended towards this but were not statistically significant.

#### 5.4.3 Energy Balance

Figure 5.1 illustrates the energy balance for individual cows of each breed group by WOL. Visual inspection of the graphs illustrates a few evident trends. A majority of animals start in negative energy balance at the beginning of lactation. Ten cows (six HH and four JH) in this analysis did not start in negative energy balance. One explanation could be that the experiment did not start until week three into lactation, which may have given some cows enough time to establish a weekly positive balance. First parity animals mobilize less energy from body tissue than multiparous animals (Friggens et al., 2007) so it is not surprising that not all cows had negative EB at some point in first lactation.

Inspection of the overall EB curves for each cow reveals disjointedness for HJ, JH, and JJ breed groups between the weeks 27 and 28. This was caused by the stage effect in the model as week 27 was the end of stage three, and week 28 was the beginning of stage four for  $NE_L$  consumed. A different stage structure was tested using three stages of lactation weeks 3 to 12, weeks 13 to 24, and weeks greater than 25, but resulted in a higher Akaike's information criteria and still had an evident change in energy prediction when moving between segments. The disjointedness was more pronounced for JJ because the stage of lactation by group solution was proportionally lower for energy consumed in the last two stages than the other breed groups. Friggens et al. (2007) also found that Jerseys behaved differently, but found that it was in early lactation and reported that there was an interaction between the breeds and stages within parity. They found that Jerseys mobilized more energy in early lactation of first parity than expected from the differences between the breeds at the later stages of lactation. The drop in energy intake in Jerseys in our study could also be due to the small sample of Jersey animals in the study.

Additionally, there were three cows that appear to have EB curves that really distance themselves from the contemporaries towards the end of lactation. The most likely cause was the use of random regression to estimate curves with incomplete

lactation records on the individual. One of these cows was a HH that died during the project. Intakes were recorded when she was alive and healthier and her body weights were recorded up until her removal from the farm. The problem results because random regression assumes that she continued to lose body weight for the entire lactation, rather than weight loss prior to her removal from the farm. Her body weight curves decline. Her intakes, however, were collected when she was in better health and thus her consumption curve does not decline. The result is that her overall EB curve remained positive and continued on an increasingly positive but distorted trend through the rest of the lactation. The two JH cows that spread further apart from the breed group average EB had not finish a complete 305 day cycle and were losing weight at the beginning of lactation. It is likely that EB is overestimated at the tail end of the lactation. The flair in EB in the last few weeks of lactation for all breed groups was partially due to cow differences in pregnancy requirements, as the NRC model assumes a 0 pregnancy requirement until animals are 190 days pregnant. The impact would only apply to the last few weeks of the lactation.

There were four cows that never reached positive energy balance in a week (2 HH and 2 HJ from 2 different sires). One of these cows did not survive to second lactation. The other three cows all had body condition scores that did not drop more than a point during lactation and all three of the cows conceived and calved for a second time within 18 months of the first calving. It is unlikely that these cows were in negative weekly EB for all 41 weeks as they gained body weight, conceived, and still produced milk. A possible explanation could be that they did eat as much when they were in the Calan doors as when they were under routine herd management. The Calan doors could have influenced their intakes, causing it to appear that they were not eating enough to support the production and BW recorded when they were not in the Calan doors.

There were 27 cows that did not reach an overall positive energy balance by the end of lactation. There were 7, 9, 8, and 3 HH, HJ, JH, and JJ in which 11 are from the same Holstein sire and 7 are from the same Jersey sire. This is consistent with the work of Coffey et al. (2003) which found that daughters from certain sires were in chronic negative energy balance through the lactation and never fully regained the energy lost in early lactation by the end of lactation. Our data support this observation, as two thirds of

the cows that did not reach a positive TEB by the end of lactation were sired by the same two bulls. Half of the animals that never reached positive EB weighed less at the end of lactation than at the beginning, the others could possibly be more efficient at using or converting energy.

Table 5.5 represents the analyses for week to positive energy balance, week to cumulative energy balance, TEB, and TEB<sub>21</sub>. The weeks in which cows returned from a daily negative EB to positive did not differ significantly between breed groups with solutions being week 12, 14, 11, and 13 for HH, HJ, JH, and JJ. Results are consistent with the 10 and 11 week return to positive balance reported by Coffey et al. (2002). Significant effects in the model included year-season freshening group and a linear and quadratic term for age at calving. The linear and quadratic term for age at calving indicated that intermediate ages at calving reached week return to positive energy balance faster than younger and older calving animals. The analysis of return to cumulative positive energy showed no significant effects. The least square means were 20, 26, 24, and 28 for HH, HJ, JH, and JJ, respectively. The breed group effect for TEB was significant ( $P < 0.10$ ), however, when a multiple comparison adjustments were made no breed groups were different from each other. The TEB for the lactation was 480, 146, 410, and 125 NE<sub>L</sub> (Mcal) for HH, HJ, JH, and JJ. These numbers are quite small relative to the TEC in Table 5.3. Freshening group was also a significant effect for TEB, but the linear and quadratic effects for age at calving were not. There were no significant effects for TEB<sub>21</sub>. The differences for TEB are consistent with results in Table 5.4 in that we were not able to account for a certain percent of energy in all breed groups.

Body condition scores were not used for the EB calculations, however, the body condition scores across stages of lactation were analyzed by breed group to investigate possible body lipid changes. The significant effects in the model were breed group, stage, and year-season freshening group. The linear and quadratic terms for age at calving and the stage by breed group interaction were not significant. The breed groups solutions were  $2.79 \pm 0.06$ ,  $2.80 \pm 0.07$ ,  $2.59 \pm 0.07$ , and  $2.83 \pm 0.10$  for HH, HJ, JH, and JJ. The HH and HJ carried more body condition than the JH group ( $P < 0.10$ ). These results do not agree with Heins et al. (2008b), where the crossbreds had a higher BCS. The solutions for stage of lactation, defined in two month periods after freshening were



2.56 ± 0.05, 2.65 ± 0.05, 2.77 ± 0.05, 2.90 ± 0.05, and 2.94 ± 0.05 for stage 1, stage 2, stage 3, stage 4, and stage 5, respectively. All of the stages were different from each other.

The regression of EB on TEP was significant ( $P < 0.05$ ). When TEP increased, EB decreased with an estimate of -0.32 NE<sub>L</sub> (Mcal) and standard error of 0.01 NE<sub>L</sub> (Mcal). Interpretation is that for every increase in one NE<sub>L</sub> (Mcal) for milk production, we would expect the energy balance for that day to decline by 0.32 NE<sub>L</sub>. This is consistent with results from (Coffey et al., 2004) who found that cows with higher milk production had higher mobilization of body tissue.

## 5.5 CONCLUSIONS

The crossbreds ate the same amount or less energy than the HH, required less energy for maintenance than the HH, and required the same or less for growth from the HH, but gave the same energy in milk as the HH. The non-significant trend was that the proportion of energy consumed allocated to milk production was greater in the HJ, JH, and JJ groups. This could be due to the HH allocating more energy into maintenance, where differences were significant between JH and HH, and growth where differences were numerically, but not statistically different. Most of the energy balance traits were not significantly different between the breed groups. The trend was for the HH and JH to have a larger EB at the end of the lactation. In a milk component based market system, the crossbreds could be very profitable, as they produced the same energy of milk as the HH and required less maintenance energy in first lactation. There is potential for the energy partitioned to growth in first lactation HH to become a more favorable partitioning of that energy to production in later lactations. However, an early maturing animal favors a more rapid return on investment in rearing expenses. The Jersey numbers were limited in this study and additional research is required to establish economic differences between breed groups.

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**Table 5.1. Daily means for HH, HJ, JH, and JJ for milk production, milk components, body weight, days pregnant, DMI, and NE<sub>L</sub> required for milk production**

Variable	HH <sup>1</sup>		HJ		JH		JJ	
	$\bar{x}$	range	$\bar{x}$	range	$\bar{x}$	range	$\bar{x}$	range
AAC (d) <sup>2</sup>	755	628-962	714	587-893	720	624-866	762	684-884
BW (kg) <sup>3</sup>	577	441-790	518	373-700	494	369-617	412	337-550
DIM (d) <sup>4</sup>	156	18-305	159	18-305	155	18-305	158	18-305
DMI (kg/d) <sup>5</sup>	21.6	5.4-33.7	20.6	3.1-31.2	20.3	3.4-31.5	17.3	4.7-22.8
DPREG (d) <sup>6</sup>	50	0-234	57	0-233	55	0-232	66	0-231
Milk (kg/d)	31.7	5.6-58.1	28.2	4.4-58.4	29.7	5.2-53.4	22.6	4.6-36.0
Fat % <sup>7</sup>	3.47	1.6-6.7	4.19	2.5-6.5	3.79	1.9-6.8	4.83	3.1-7.9
Protein % <sup>7</sup>	3.03	2.40-4.20	3.32	2.5-4.8	3.22	2.6-4.1	3.48	2.6-4.5
NE <sub>L</sub> (Mcal) Milk	21.6	4.3-50.2	21.5	3.6-44.7	21.4	3.6-38.8	18.7	4.5-34.3

<sup>1</sup> breed of sire listed first

<sup>2</sup> ACC = age at calving

<sup>3</sup> BW = body weight calculated as a weekly average

<sup>4</sup> DIM = days in milk

<sup>5</sup> DMI = dry matter intake, daily

<sup>6</sup> DPREG = days pregnant

<sup>7</sup> Measured monthly

**Table 5.2. Assumptions of mature body weight and calf birth weight made for HH, HJ, JH, and JJ for NE<sub>L</sub> (Mcal) energy calculations for pregnancy and growth from the NRC (2001).**

Breed Group	Mature Weight (kg)	Calf Birth Weight <sup>1</sup> (kg)
HH <sup>2</sup>	680	42.7
HJ	635	39.9
JH	635	39.9
JJ	522	32.7

<sup>1</sup> calculated as 0.06275 x mature weight (Appendix A)

<sup>2</sup> breed of sire listed first



**Table 5.3. Cumulative predicted NE<sub>L</sub> consumed, and NE<sub>L</sub> (Mcal) required for growth, maintenance, pregnancy, and production for Holstein, Jerseys, and reciprocal crosses over week 3 to week 43 of the first lactation**

	HH <sup>1</sup>		HJ		JH		JJ	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
	-----NE <sub>L</sub> (Mcal)-----		-----NE <sub>L</sub> (Mcal)-----		-----NE <sub>L</sub> (Mcal)-----		-----NE <sub>L</sub> (Mcal)-----	
Intake (TEC)	9722 <sup>a</sup>	110	9308 <sup>b</sup>	132	9410 <sup>a,b</sup>	129	7535 <sup>c</sup>	200
Growth (TEG)	543 <sup>a</sup>	39	498 <sup>a,b</sup>	46	390 <sup>b</sup>	46	325 <sup>b</sup>	70
Maintenance (TEM)	2664 <sup>a</sup>	21	2484 <sup>b</sup>	26	2416 <sup>b</sup>	25	2057 <sup>c</sup>	39
Pregnancy (TEPR)	33	8	39	10	41	10	25	15
Production (TEP)	6003 <sup>a</sup>	137	6141 <sup>a</sup>	164	6154 <sup>a</sup>	161	5004 <sup>b</sup>	249

\*breeds with different superscripts are significantly different  $P < 0.10$

<sup>1</sup> breed of sire listed first

**Table 5.4. Least square means for predicted percent of energy consumed used for growth, maintenance, pregnancy, and production for Holsteins, Jerseys, and reciprocal crosses over week 3 to week 43 of first lactation**

	HH <sup>1</sup>		HJ		JH		JJ	
	Mean %	SE	Mean %	SE	Mean %	SE	Mean %	SE
Growth	5.6	0.4	5.5	0.5	4.2	0.5	4.4	0.8
Maintenance	27.6 <sup>b</sup>	0.4	26.8 <sup>a,b</sup>	0.5	25.8 <sup>a</sup>	0.5	27.2 <sup>a,b</sup>	0.7
Pregnancy	0.4	0.1	0.4	0.1	0.4	0.1	0.4	0.1
Production	61.9	1.2	65.6	1.5	65.4	1.4	66.1	2.2
Total <sup>2</sup>	95.3	1.1	98.3	1.3	95.8	1.3	98.0	2.0

\*breeds with different superscripts are significantly different  $P < 0.05$

<sup>1</sup> breed of sire shown first

<sup>2</sup> the total energy accounted for by the least square means for (energy used / energy consumed) \*100

**Table 5.5. Least squares means for week to positive weekly energy balance, week to total cumulative energy balance, total energy balance, and total energy balance at week 21 for first lactation Holstein, Jerseys, and reciprocal crosses**

	HH <sup>1</sup>		HJ		JH		JJ	
	Mean	SE	Mean	SE	Mean	SE	Mean	SE
PEBW <sup>2</sup> (wks)	12.2	1.3	14.7	1.6	11.7	1.5	13.5	2.4
WPEB <sup>3</sup> (wks)	20.5	2.2	26.7	2.7	24.0	2.6	28.8	4.1
TEB <sup>4</sup> (NE <sub>L</sub> (Mcal))	408	104	145	125	410	123	125	190
TEB <sub>21</sub> <sup>5</sup> (NE <sub>L</sub> (Mcal))	72.5	54.7	-49.5	65.6	0.3	64.4	-163.9	99.5

<sup>1</sup> breed of sire listed first

<sup>2</sup> PEBW = first week where energy balance was positive

<sup>3</sup> WPEB = Week where cumulative energy balance was positive

<sup>4</sup> TEB = total cumulative energy balance

<sup>5</sup> TEB<sub>21</sub> = total cumulative energy balance at week 21

**Figure 5.1.** Energy balance profiles by week of lactation (WOL) for each breed group for first lactation. WOL is week of lactation and breed group is represented as sire breed by dam breed (e.g. HJ is Holstein sired out of Jersey dam)

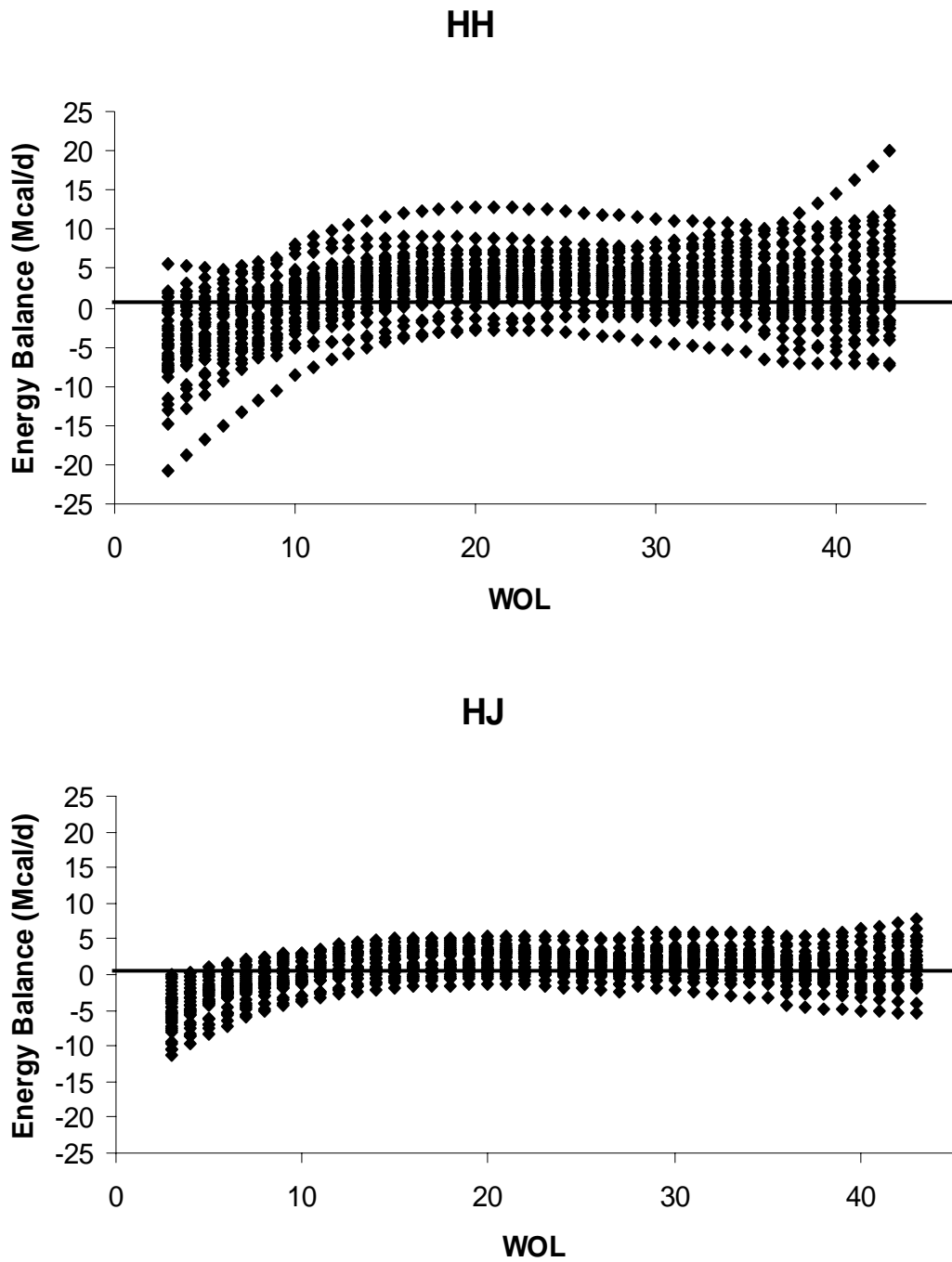
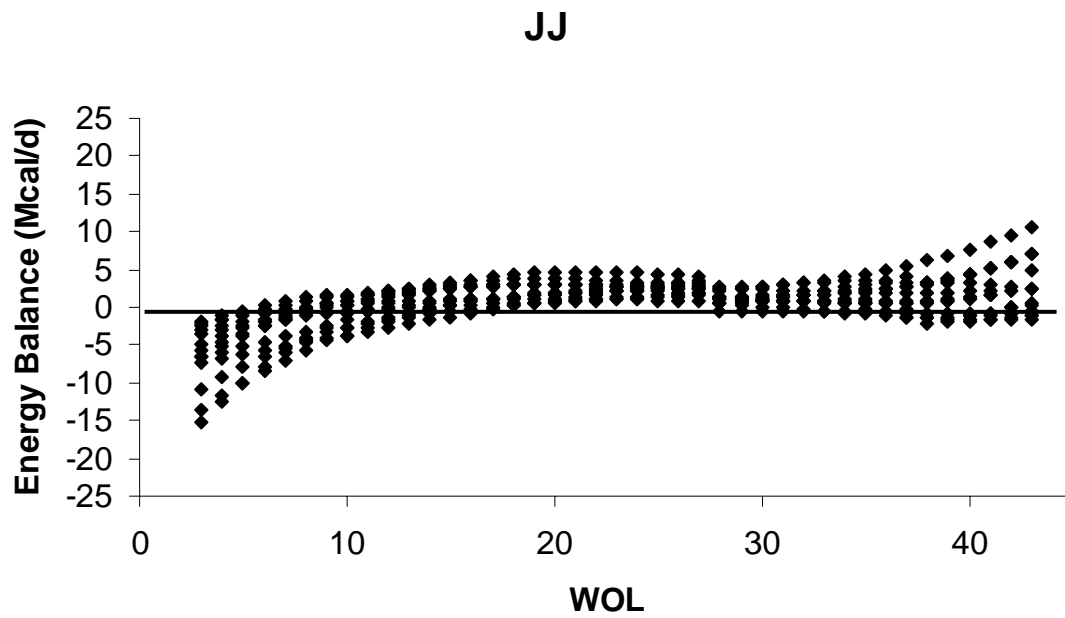
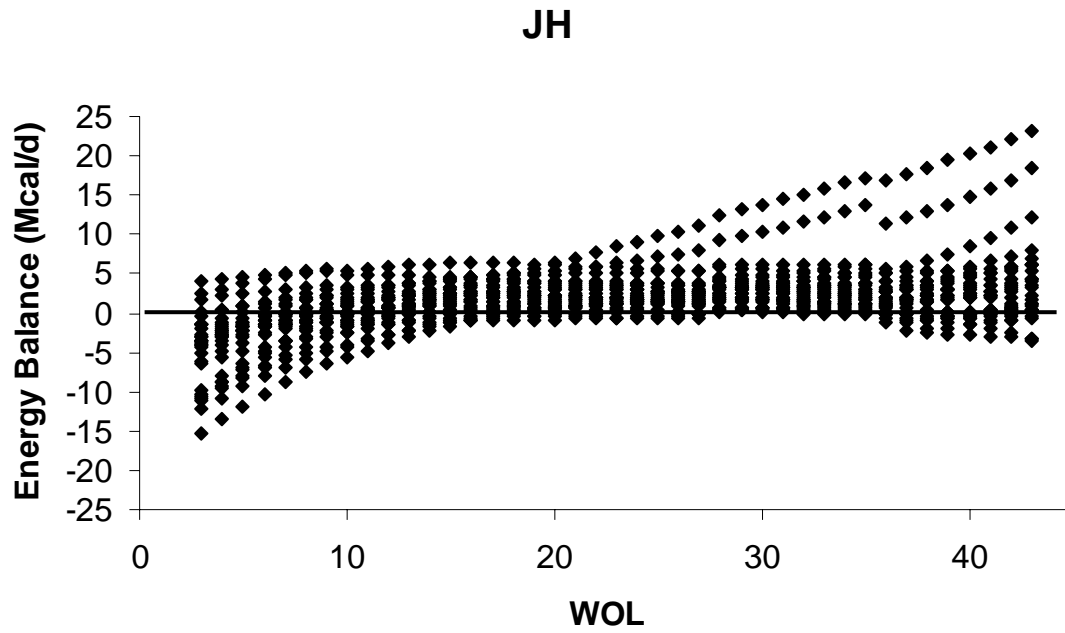


Figure 5.1. Continued



## 5.7 APPENDIX A

These equations are from the NRC (2001)

### Lactation Requirements

$$NE_L(\text{Mcal/kg}) = 0.0929 \times \text{Fat \%} + 0.0563 \times \text{True Protein \%} + 0.192$$

### Pregnancy Requirements

$$NE_L (\text{Mcal/d}) = [(0.00318 \times D - 0.0352) \times (\text{CBW}/45)]/0.218$$

Where

D is day of gestation between 190 and 279

CBW is calf birth weight assumed to be 42.57, 39.73, 39.73, and 32.64 kg for HH, HJ, JH and JJ with

$$\text{CBW} = 0.06275 * \text{MW}$$

### Maintenance Requirements

$$NE_L (\text{Mcal/kg}) = 0.080 * \text{MBW}$$

Where MBW is metabolic body weight ( $\text{BW}^{0.75}$ )

### Retained Energy Calculations

$$\text{MSBW} = (\text{Mature Shrunk body weight}) = 0.96 \times \text{Mature Weight}$$

Mature weight for the different breeds was assumed to be 680.40, 635.04, 635.04 and 521.64 kg for HH, HJ, JH and JJ respectively.

$$\text{SBW} = \text{Shrunk body weight} = 0.96 \times \text{BW}$$

SRW = standard reference weight

SRW to MSBW = 478 / MSBW

EQSBW = Equivalent shrunk body weight (kg) and CW = Conceptus weight

$CW = (18 + ((\text{days pregnant} - 190) \times 0.665)) \times (\text{calf birth weight}/45)$

$EQSBW = (SBW - CW) \times \text{SRW to MSBW}$

EQEBW = size-scaled empty body weight = 0.891x EQSBW

EQEBG = size-scaled empty body weight gain = 0.956 x Average daily gain

Retained Energy (RE) = 0.0635 x (EQEBW<sup>0.75</sup>) x (EQEBG<sup>1.097</sup>)

## CHAPTER 6

### Energy balance and relationship to health and fertility in first lactation

#### Holsteins, Jerseys, and reciprocal crosses

##### 6.1 ABSTRACT

A total of 118 first lactation Holsteins (HH), Jerseys (JJ), and crossbreds (HJ and JH with sire breed listed first) had observations for energy intake at week 15 of lactation ( $EI_{15}$ ), energy balance calculated from energy intake and estimates of expenditures at week 15 of lactation ( $EB_{15}$ ), and recordings of health problems and pregnancy. Data included 44, 32, 29, and 13 HH, HJ, JH, and JJ cows, respectively. Displaced abomasum (DA), ketosis (KET), mastitis (MAST), and metritis (MET), were recorded in the first 100 days of lactation with an incidence of the disease receiving a one and no incidence receiving a zero. Pregnancy (PREG) at day 150 was recorded as one if a cow had conceived by day 150 and a zero if she had not. Logistic regression was used to analyze health and fertility with fixed effects in the model including breed group, linear and quadratic effects for age at calving (AAC), year-season of freshening group, and  $EB_{15}$ . A general linear model was used to analyze the response variables of  $EB_{15}$  and  $EI_{15}$  with explanatory variables of year-season of freshening group, linear and quadratic effects of AAC, breed group, and health events (MAST, DA, MET, and KET) which were included individually in separate models. Breed group effects were significant in the occurrence of MAST and MET. The significant odds ratios for MAST were 15.5, 11.4, 11.9 for the JJ, JH, and HJ compared to HH. Thus, JJ cows were 15.5 times more likely to have an incidence of MAST than the HH. Significant breed group differences for MET showed that HJ were 13.7% and the JH were 4% as likely as the HH to have an occurrence of MET. No other breed group effects were significant in any of the disease and PREG models. The linear and quadratic terms for AAC were significant for MAST and PREG. Intermediate AAC had a higher probability of MAST, but also had a higher probability of becoming PREG by day 150. No other effects were significant for disease and PREG models. The results for health disease impacts on  $EB_{15}$  were not significant. An



occurrence of a DA and/or KET decreased  $EI_{15}$ . This study revealed few breed group differences for health traits,  $EB_{15}$  was not a factor, but  $EI_{15}$  was decreased by certain health diseases.

(Keywords: dairy cows, energy balance, health)

## 6.2 INTRODUCTION

The high productivity of dairy cows has created increasing problems in fertility and health (Dunklee et al., 1994; Collard et al., 2000; Berry et al., 2003). Some producers have turned to crossbreeding, to overcome some of these problems (Weigel and Barlass, 2003). Crossbreeding has shown benefits for fertility, survivability, and milk components and could have advantages in health disorders (VanRaden and Sanders, 2003; Heins et al., 2006; Anderson et al., 2007). Several studies have indicated that crossbreds have fewer health and lameness problems than purebred Holsteins (Heins et al., 2006; Anderson et al., 2007). Crossbreds have advantages in reproductive performance (Anderson et al., 2007; Heins et al., 2008). Anderson et al. (2007) found that Jersey- Holstein crosses had 22 fewer days open when compared to the Holsteins in a pen study. Heins et al. (2008) also found JH crosses to have fewer days open than their Holstein contemporaries. There is limited literature on crossbreds and incidence of health disorders, however, there is evidence of genetic control on health traits (Zwald et al., 2004).

Energy balance in early lactation has been linked with health (locomotive and digestive) and fertility problems (De Vries et al., 1999; Collard et al., 2000). Prolonged periods of negative energy balance can increase the use of body reserves which can have detrimental effects for fertility and health (Hansen, 2000; Banos et al., 2006). Energy balance differences between the breeds or a breed by energy balance interaction could potentially have an impact on health and fertility problems.

Studies have shown genetic difference for energy balance between selection lines and breed groups (Coffey et al., 2004; Friggens et al., 2007). Coffey et al. (2004) found that cows selected for high productivity in milk production were predisposed to use body energy reserves to support production. Friggens et al. (2007) found significant

differences between Danish Holstien, Danish Red, and Jerseys for energy balance. Banos et al. (2006) found a significant genetic correlation of -0.18 for cumulative energy balance at week 6 of lactation and somatic cell counts in the first two lactations. There could also be differences in how energy balance profiles affects health and fertility between breeds.

The literature included few results of the relationships between breed groups, energy balance, and health disorders. Data sets of energy balance and health disorders are rare because of the difficulties of the collection of intake data and accurate recording of health disorders. The first objective of this study was to determine if there were breed group differences in the first 100 days of lactation for displaced abomasums, mastitis, metritis, or ketosis and if early lactation energy balance had an impact. The second objective was to investigate the impacts of health disorders on energy consumption and energy balance. The final objective was to determine if breed group and/or energy balance had an effect on pregnancy status by 150 days in milk in first lactation Holstein, Jersey, and reciprocal crosses managed together.

## **6.3 MATERIALS AND METHODS**

### *6.3.1 Data*

This study included 118 first lactation animals with 44, 32, 29, and 13 HH, HJ, JH, and JJ cows, respectively. All of the animals were part of the Virginia Tech crossbreeding project and data were collected between July 2005 and March 2008. The breed groups were housed, fed, and milked together. The energy balance term used was cumulative energy balance at week 15 ( $EB_{15}$ ) of first lactation. Energy balance was calculated as the energy consumed minus energy needed for growth, maintenance, and milk production and with energy requirements calculated according to NRC (2001) calculations. Further details on energy balance calculation can be found in Chapter 5. Energy to support pregnancy does not affect this variable because cows had to be 190 days pregnant before there was an adjustment for pregnancy on energy balance (NRC, 2001). Cumulative energy intake at week 15 ( $EI_{15}$ ) was defined as the total amount of energy consumed from week 3 to week 15. Both  $EB_{15}$  and  $EI_{15}$  included information from week three in lactation to week 15. There was no collection of feed intakes in the

first two weeks of lactation, therefore no energy intake was predicted before week three. A full explanation of the animals in the project and calculation of energy balance can be found in Chapter 5.

Health events were recorded at the time of occurrence in PC DART™ (DRMS, Raleigh, NC). Veterinary care for The Virginia Tech dairy was provided by veterinarians from the Virginia Maryland College of Veterinary Medicine. Health data were retrieved from PC-DART for further statistical analyses. Data retrieved for health analyses included the first incidence in the first 100 days of lactation for ketosis (KET), metritis (MET), displaced abomasum (DA), and mastitis (MAST). The DA included both right and left displaced abomasums. The MAST events were recorded as treatment of any udder infections. Pregnancy (PREG) was defined as cow conceiving by 150 DIM and was determined by breeding dates, pregnancy check, and, where possible and applicable, verified by a subsequent calving. Ketosis, DA, MET, MAST, and PREG were recorded as binary data where a zero was recorded if a cow did not have the disease (or was not pregnant) and one was recorded if a cow did have the disease. Table 6.1 shows the incidences of DA, MET, MAST, KET, and PREG for each of the breed groups. The mean percentages for KET and MAST were similar to Zwald et al. (2004) where the mean percentages were 10 and 20 for KET and MAST, compared to our overall mean percentage of 8 and 18. Our DA mean percentage was numerically higher (14 verses 3), but our MET was lower (10 verses 20) than the mean percentages reported by Zwald et al. (2004). Table 6.2 shows incidences by month of lactation for the first 100 days in milk. A majority of the disease occurrences happened within the first month of lactation.

### 6.3.2 Statistical Analyses

Incidence data corresponding to each health disorder and pregnancy were analyzed separately. A linear logistic regression model using the PROC LOGISTIC procedure of SAS (SAS Institute, 2004) was used to account for the binary nature of the data. The model was:

$$\eta_{ijn} = \mu + YS_i + G_j + AAC_n + AAC_n^2 + EB_{15n} + e_{ijn} \quad [1]$$

where  $\eta$  was the logit of observing the disease from the  $n^{\text{th}}$  cow in the  $i^{\text{th}}$  year-season of freshening group,  $j^{\text{th}}$  genetic group (breed group), with the  $n^{\text{th}}$  cows age at calving (AAC) and  $EB_{15}$ , and  $e_{ijn}$  was the random error term.

A general linear model using the PROC GLM procedure of SAS (SAS Institute, 2004) was used to investigate the impacts of health events on  $EB_{15}$  and  $EI_{15}$ . The model was:

$$Y_{ijsn} = u + YS_i + G_j + AAC_n + AAC_n^2 + H_s + e_{ijsn} \quad [2]$$

where  $Y_{ijsn}$  was the observation (either  $EB_{15}$  or  $EI_{15}$ ) from the  $n^{\text{th}}$  cow in the  $i^{\text{th}}$  year-season of freshening group,  $j^{\text{th}}$  genetic group (breed group), age at calving (AAC),  $s$  with the  $H$  health event of interest (run separately for KET, MAST, MET, and DA), and the random error term  $e_{ijsn}$ .

## 6.4 RESULTS AND DISCUSSION

### 6.4.1 Health and Fertility Events

Results of the logistics regression for DA, MAST, MET, KET, and PREG are found in Table 6.3. There were significant differences between breed groups for MAST and MET ( $P < 0.10$ ). The significant odds ratios for MAST were 17.8, 11.3, 11.3 with confidence intervals of 2.1 to 144.8, 1.8 to 71.1, and 1.9 to 67.9 for the JJ, JH, and HJ in comparison to the HH. In other words, the JJ were 15.5 times more likely than HH to have an incidence of mastitis. There were no significant differences for MAST between the JJ, HJ, and JH groups. Probabilities of having an incidence of MET also differed between breed groups. The JH and HJ had odds ratio of 0.152, and 0.049 with confidence intervals of 0.025 to 0.916, and 0.004 to 0.592 in comparison to the HH. Thus, the JH were 13.7% as likely as the HH to have an incidence of MET. The HH and JJ were not different from each other for MET and the HJ, JH, and JJ were not different from each other. There were no significant breed group effects for KET, DA, and PREG.

There were no significant differences between breed groups in our data for PREG. There has been evidence of significant differences between JH crossbreds and HH for fertility in the literature (Anderson et al., 2007; Heins et al., 2008). Anderson et al. (2007) found fewer days open in the crossbreds compared to the pure Holstein. Our definition of fertility required a cow to be pregnant by day 150 and would not necessarily account for

differences between days open. Heins et al. (2008) found a higher portion of JH were pregnant (75%) than pure Holsteins (59%) by 150 days in milk. These results are different, but all cows in this study were from a high input freestall herd where as a majority of the cows in Heins et al. (2008) were at a low input grazing herd.

Environmental differences in the two studies would affect the results.

The linear and quadratic term for AAC were significant for MAST and PREG. Figure 6.1 shows the effect of AAC on MAST and Figure 6.2 represents the effect of AAC on PREG. Younger and older calving animals had a lower probability of MAST, however, intermediate age calving animals had a higher probability of conceiving by day 150 in milk. Year-season of freshening group was not significant in any of our analyses.

EB<sub>15</sub> did not significantly effect the likelihood of any disease or PREG status. In contrast, De Vries et al. (1999) reported that large energy deficits in early lactation delayed first detected estrus. The study investigated the return to estrus, our study measured pregnancy status at 150 days, which are two different measures of fertility. De Vries et al. (1999) also found that first lactation animals had less energy deficit than multiparous cows. Our study of first lactation performance may not have involved the extreme energy deficits in early lactation that would hinder fertility. Additionally, our measure of energy balance did not include the first two weeks of lactation which are typically when the cow experiences the largest deficit in energy balance.

Results for MAST and PREG do agree with Collard et al. (2000) who found no statistical significance between energy balance at day 100 in lactation and MAST and reproductive problems. Banos et al. (2006) found significant genetic correlations for energy balance and somatic cell count but also found energy balance traits to be unrelated to clinical mastitis. Collard et al. (2000) did, however, find a relationship between the days in negative energy balance and reproductive problems. Longer days in negative energy balance increased the probability of reproductive problems. Veerkamp et al. (2000) found a low phenotypic correlation between energy balance (in the first 100 days) and interval to first luteal activity (a measure of fertility), but did find stronger genetic correlations between the traits.

#### 6.4.2 Health and Pregnancy Influence on Energy Balance and Intake

The results for the analyses of health impacts on  $EI_{15}$  and  $EB_{15}$  are located in Table 6.4. An incidence of DA decreased  $EI_{15}$  by  $38.69 \pm 9.66$  Mcal while a ketosis event decreased  $EI_{15}$  at week 15 by  $24.17 \pm 11.38$  Mcal. Health problems that were digestive in nature affected feed intakes enough to significantly reduce cumulative energy intake by week 15 in lactation.

There were no significant effects of any of the health variables on  $EB_{15}$ . Cumulative energy balance was measured at week 15, while the health events had to occur within the first 100 days. Additionally, feed intakes were not collected on cows that were clinically sick so estimates of feed intake came from cows that were considered healthy enough to be in the Calan doors. Our energy balance term would have been impacted by health diseases in the early weeks of lactation and may have had enough time to balance by week 15. Additionally, milk production would have decreased rapidly after decreased intakes and/or disease which would have kept overall energy balance level.

Breed group and year-season freshening group significantly affected  $EI_{15}$ . This is the expected result because breed groups were statistically different for energy consumed in the analysis from Chapter 5. Additionally, there were no significant effects for  $EB_{15}$ . Again this was not surprising as the cumulative energy balance at week 21 showed no significant differences between the breed groups (Chapter 5). Overall,  $EI_{15}$  was impacted by breed group and health disorders that affected the digestive system, but compensatory reduction in milk yield left  $EB_{15}$  unaffected by factors considered in this analysis.

### 6.5 CONCLUSIONS

$EB_{15}$  did not impact the occurrence of MAST, MET, KET, DA, and PREG. Age at calving did have a significant effect with intermediate ages at calving increasing the probability of MAST, but also increasing the probability of conception by 150 days in milk. The intermediate optimum age at calving had the highest probability of conception by 150 days in milk. The HJ, JH, and JJ were more likely to have an occurrence of MAST than the HH. The crossbreds (HJ and JH) were less likely to have an occurrence of MET than the HH. There were no differences between the breed groups for KET, DA,

and PREG. Health disorders did not impact energy balance at week 15 of lactation. Health disorders that affected the digestive system (DA and KET) reduced the total amount of energy consumed by week 15 of lactation. We saw a small difference in disease incidences by breed group with a small sample size. Energy balance was not affected by disease, but energy intake was. Milk yield energy declined enough to “offset” losses in intake, leaving energy balance unaffected by disease in this small sample.

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**Table 6.1. Incidence and percentages of displaced abomasums, mastitis, metritis, ketosis, and pregnancy in the first 100 days in first lactation Holsteins, Jerseys, and reciprocal crosses**

	HH <sup>1</sup>		HJ		JH		JJ		Total	
	n = 44		n = 32		n = 29		n = 13		n = 118	
	Incidence	Percentage	Incidence	Percentage	Incidence	Percentage	Incidence	Percentage	Incidence	Percentage
DA <sup>2</sup>	6	14%	6	19%	1	3%	0	0	13	11%
Ketosis	4	9%	3	9%	2	7%	1	8%	10	8%
Mastitis	2	5%	9	28%	7	24%	4	31%	22	19%
Metritis	9	20%	1	3%	2	7%	0	0	12	10%
Pregnancy <sup>3</sup>	24	55%	20	63%	19	66%	11	85%	74	63%

<sup>1</sup> breed of sire listed first

<sup>2</sup> DA = displaced abomasums

<sup>3</sup> defined as conceived by day 150

**Table 6.2. Health disease incidences by days in milk (DIM) for displaced abomasums, mastitis, metritis, ketosis, for the first 100 days in first lactation Holsteins, Jerseys, and reciprocal crosses**

Disease	Days to first occurrence		
	< 30 DIM <sup>1</sup>	30 to 59 DIM	60 to 100 DIM
Displaced Abomasum (DA)	11	1	1
Ketosis (KET)	8	2	0
Mastitis (MAST)	10	10	2
Metritis (MET)	11	0	1

<sup>1</sup> DIM = days in milk

**Table 6.3. Probability of a greater chi square statistic for the response variables for DA, ketosis, mastitis, metritis in the first 100 days and pregnancy in the first 150 days in first lactation of Holsteins, Jerseys, and reciprocal crosses**

	DA <sup>1</sup>	Ketosis	Mastitis	Metritis	Pregnancy
AAC <sup>2</sup>	0.095	0.158	0.023	0.298	0.043
AAC*AAC	0.096	0.162	0.025	0.290	0.032
Breed	0.335	0.640	0.031	0.055	0.491
EB <sub>15</sub> <sup>3</sup>	0.139	0.184	0.168	0.435	0.930
YS <sup>4</sup>	0.607	0.362	0.837	0.966	0.196

<sup>1</sup> DA = displaced abomasum

<sup>2</sup> AAC = age at calving

<sup>3</sup> EB<sub>15</sub> = energy balance at week 15

<sup>4</sup> YS = year – season of freshening

**Table 6.4. Probability of a greater F statistic for EB<sub>15</sub> and EI<sub>15</sub> on the first 100 days in first lactation of Holsteins, Jerseys, and reciprocal crosses**

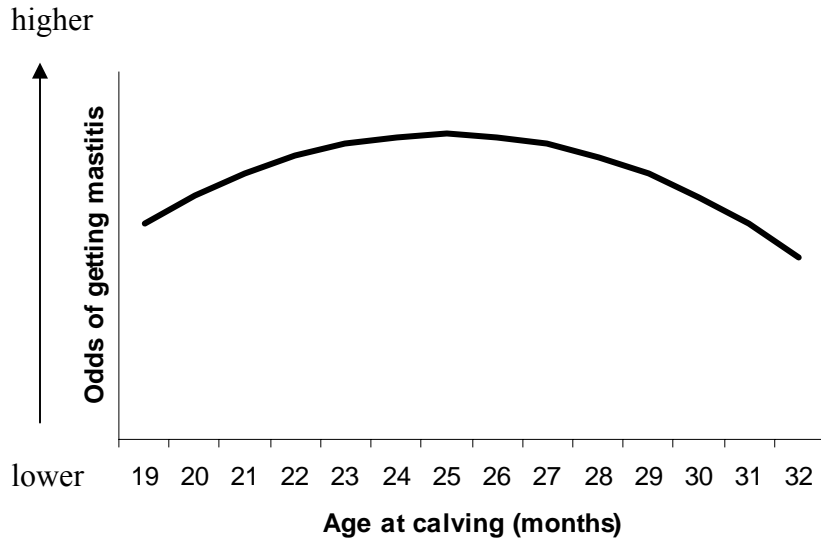
Response variable/ Explanatory variable	EB <sub>15</sub> <sup>1</sup>	EI <sub>15</sub> <sup>2</sup>
DA <sup>3</sup>	0.169	0.001
Ketosis	0.208	0.036
Mastitis	0.309	0.226
Metritis	0.622	0.589

<sup>1</sup> EB<sub>15</sub> = cumulative energy balance at week 15 of lactation

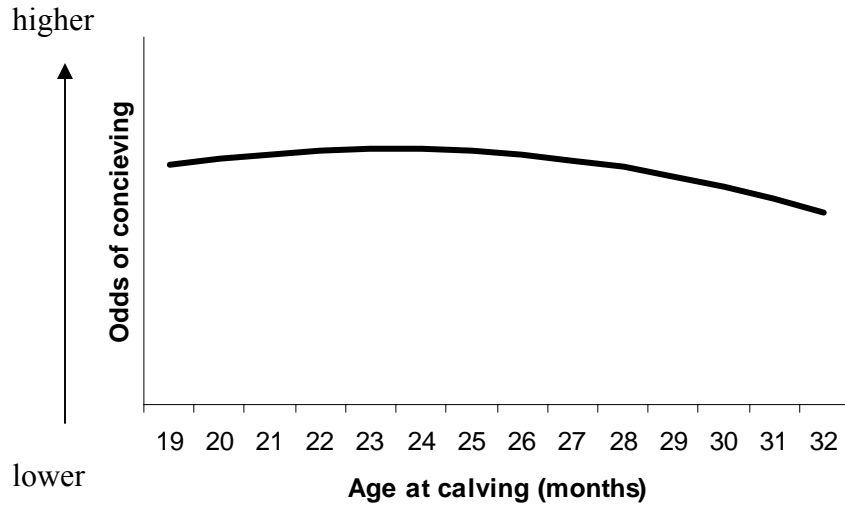
<sup>2</sup> EI<sub>15</sub> = cumulative energy intake at week 15 of lactation

<sup>3</sup> DA = displaced abomasum

**Figure 6.1.** Effect of age at calving on the probability of having an incidence of mastitis in the first 100 days of first lactation Holstein, Jersey, and reciprocal crosses.



**Figure 6.2.** Effect of age at calving on the probability of conceiving in the first 100 days of first lactation Holstein, Jersey, and reciprocal crosses.



## CHAPTER 7

### General Conclusions

These studies were from a designed crossbreeding experiment of first lactation Holsteins, Jerseys, and reciprocal crosses. The studies reported here provided evidence that the breed groups (HH, HJ, JH, and JJ – sire breed listed first) differed in prediction of dry matter intake, energy consumption and utilization, and some health disorders in first lactation.

There were breed group differences for dry matter intake (DMI) prediction equations. The NRC (2001) model overestimated consumption in the HJ, JH, and JJ groups and underestimated consumption in the HH. This could be problematic when comparing the breed groups on an economic basis because the HH would appear to consume less and the other breed groups consume more than actual. The DMI prediction equations developed in this dissertation included significant breed group effects, even after accounting for energy in milk and body weights. The importance of this finding is that even after scaling for body weight and milk production, there were additional adjustments for breed group which should be considered when developing rations for mixed or non-Holstein herds.

The energy balance traits such as weeks to positive energy balance, energy balance at week 21 and cumulative energy balance did not differ significantly between breed groups, however, there were breed group differences for total energy consumed, total energy required for maintenance, total energy required for production, and total energy for growth. The crossbreds (HJ and JH) ate the same or less, required less energy for maintenance, and required the same or less energy for growth, but produced the same milk energy as the HH. The non-significant trend was that the proportion of energy allocated to milk production was greater in the HJ, JH, and JJ groups. This could be due to the HH allocating more energy into maintenance (only significant between JH and HH) and growth (numerically, not statistically). This is important because producers could potentially see a faster return on their investment when using HJ, JH, and JJ, but



the HH allocated more energy to growth in first lactation which could lead to more favorable partitioning of energy to production in later lactations.

There were significant breed group differences in the occurrence of mastitis and metritis. The HJ, JH, and JJ were more likely to have an occurrence of mastitis than the HH. However, the crossbreds (HJ and JH) were less likely to have an occurrence of metritis than the HH. There were no breed group differences for the occurrence of ketosis, displaced abomasum, and conception by 150 days in milk. Cumulative energy balance at week 15 did not affect nor was affected by health disorders (mastitis, metritis, ketosis, and displaced abomasum) and pregnancy. Health disorders that were digestive system disorders (displaced abomasum and ketosis) reduced the total amount of energy consumed by week 15 of lactation.

These studies were phenotypic studies done on a small number of animals, with limited number of Jersey sired animals. A larger number of animals from multiparous lactations would be ideal to determine genetic parameters for the traits analyzed in this dissertation. Additionally, research is needed to establish potential economic differences between breed groups.