AN ABSTRACT OF THE THESIS OF

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Growth models developed by Pennsylvania State University (Penn State) extension services for Holstein and Jersey heifer height and weight were evaluated using OSU dairy herd heifer data. The purpose of this study was to determine the ability of the models to predict heights and weights of heifers in the OSU herd based on age. Regression lines of the models for one standard deviation above the mean and the data were compared. Residual values and biases of the models' predictions were evaluated. Mean biases were -14.96, -33.9, -5.4, and -.9.34 for Holstein weight, Jersey weight, Holstein height, and Jersey height, respectively. Linear biases were -0.1, -0.12, -0.08, and -0.07 for Holstein weight, Jersey weight, Holstein height, and Jersey height, respectively. The Penn State models did not accurately predict observed values from the OSU herd, indicating a need for further study of the models using a larger population.

Key Words: dairy, growth, heifer, development, model

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Evaluation of Current Dairy Heifer Growth Models

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I understand that my project will become part of the permanent collection of Oregon State University, University Honors College. My signature below authorizes release of my project to any reader upon request.

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Introduction

Expenses

Income on a dairy farm is generated almost exclusively from milk production with a smaller portion from the sales of replacement heifers and cows, culled cows, or bull calves. Between the birth and first lactation of a dairy heifer costs of production associated with preparing her for lactation must be considered an investment to future income. The cost of raising dairy heifers is the second greatest expense on a dairy farm (Zanton et al., 2007), accounting for 20% of the total expenses (Brown et al., 2005) and estimated in 1999 to range from $1150-1200/ head (Hoffman, et al., 2003). Nutrition costs account for at least 60% of total heifer-rearing expenses (Zanton et al., 2007), and are increasing with current feed and transportation costs. From 2001 to 2007, most energy and protein sources including corn, soybean meal, and distiller's grains approximately doubled in price across the United States while hay prices increased from approximately $115/ ton in 2002 to $165/ ton in 2008 (USDA Economic Research Service, 2008). Traditionally, forage based feeds are used in heifer programs (Zanton et al., 2007) rather than concentrates. With roughly two years of feed and care costs invested into each heifer prior to receiving any return, rearing programs must be carefully managed to maximize lifetime productivity and minimize expenses.

Challenges Associated with Growth

The challenge of maintaining structural growth and adequate body condition to maximize reproductive and mammary development is associated with heifer nutritional management. When heifers are fed during the pre-pubertal growth stage at increased rates of growth, mammary development and lifetime milk production can be irreversibly compromised (Zanton et al., 2007, Lammers et al., 1999) due to an increasing body condition relative to the size of the animal. In contrast, dairy cattle whose nutritional needs were not met during development were less productive and had an increased predisposition for calving difficulties (Zanton et al., 2007). The onset of puberty is directly correlated with growth and development; animals fed at higher rates of gain reach puberty sooner than those at lower rates of gain (Lammers et al., 1999). At the optimum growth rate, growth potential is maximized without compromising reproductive and mammary development and future lactation performance.

Feed Efficiency

With an optimal growth rate serving as a target, diets can be formulated to provide the necessary nutrients at the lowest cost (Fox et al., 1999). The result will be a diet balanced to optimize economic efficiency. This may include increasing growth rates to lower the age at first calving and formulating diets appropriately to avoid wasting money on excess nutrients during more moderate growth phases while optimizing growth during high-development stages. In turn, maximizing nutritional efficiency reduces nutrient losses (Zanton et al., 2007). The significance of heifer program contributions to while farm nutrient management may not be as great as lactating dairy cows, but the economic value of nutritionally efficient diets is increasing with increasing feed costs.

The following review of literature will further explore factors affecting the growth and development of dairy heifers and potential for cost effective nutrition strategies to optimize performance.

Management Practices

Pre-Weaning

A 1994 survey encompassing producers of 78% of the national dairy cow population revealed neonate replacement heifer nutrition as the area in greatest need of information (Heinrichs et al., 1994). In the last five years the value of dairy heifers has increased (James, 2008), due perhaps to an increased turnover rate in cow herds and higher demands for replacements. This has lead to an emphasis on decreasing calf morbidity and mortality (James, 2008). In pre-weaned dairy cattle, milk intake regulation, weaning processes, weaning time, and environmental temperature have significantly impacted growth.

Prior to weaning, milk consumption affected development. Ad libitum milk consumption resulted in delayed rumen development (Khan et al., 2007). This correlated with a linear decrease of the empty weights of rumens, reticulums, and omasums in calves with increased milk allowance (Lane and Jesse, 2007). Perirenal fat increased linearly as milk allowance increased relative to body size (Lane and Jesse, 2007). Calves that were fed milk replacer twice daily to 14 days of age, then fed either once or twice a day until time of weaning did not appear to exhibit any rumen development differences (Kehoe, 2007).

During the pre-weaning phase, calves are much more nutritionally sensitive with energy intake dictating protein requirements (Van Amburgh, 2003). During the pre-weaning growth phase, mammary development can be enhanced with a high plane of protein and energy according to increased mammary parenchymal growth for calves fed to higher rates of gain (Van Amburgh, 2003). Milk yields were increased 455- 1364 kg (1000-3000 lb) during the first lactation using accelerated growth rates during the pre-weaning phase (Van Amburgh, 2003).

The process of transitioning ruminants from a milk based diet to a forage based diet can impact animal performance. The transition diets and length of time to transition are critical to provide rumen development. Conventional feeding and weaning programs offer milk replacer daily at 10% of the body weight until weaning, when the milk replacer is diluted with water over the course of a week (Khan et al., 2007). In contrast, the step-down (STEP) method involves feeding calves milk replacer in three phases; 20% of body weight for the first two weeks, then 10% of body weight until weaning, and followed by milk replacer being diluted with water over the course of a week during weaning (Khan et al., 2007). Male calves fed using the STEP method demonstrated increased feed consumption, increased body weight and structural growth with greater metabolic and physiological rumen development compared to those fed and weaned conventionally (Khan et al., 2007). Similarly, the STEP method increased feed consumption, body weight, and structural growth in Holstein females (Khan et al., 2007).

Along with the process of weaning, the age of calves at weaning has also been evaluated. Early weaning was both convenient and economical due to lower feed and labor costs (Lane and Jesse, 2007). Early weaning (less than 7 weeks of age) does not appear to be detrimental in that calves weaned at 3,4,5 and 6 weeks did not show any variation of structural/growth measurements, blood constituents, or general health (Kehoe, 2007). However, in a study with lambs that were weaned at either 30 or 60 days, there were significant stress hormonal changes associated with weaning at 30 days, which were not apparent in lambs weaned at 60 days (Holcombe et al., 1995).

In managing the pre-weaned dairy heifer, energy and protein requirements for diet formulation, the age at weaning, and the process of weaning must be considered.

Additionally, any environmental influence on nutrient requirements should also be considered. Due to a higher surface area to volume ratio of the body, calves become cold stressed much more easily than mature cattle. Even at 50 °F, calves will become cold stressed, and adipose tissue will be mobilized when temperatures reach 32°F (VanAmburgh, 2003). Calves can also be affected by heat stress, generally resulting in decreased intake. As of 1994, few producers offered water ad libitum to heifers at 4 to 8 weeks of age when feeding forage and grain (Heinrichs et al., 1994). Thus, diet formulation and amounts offered should be adjusted to account for the influence of environmental conditions on basic nutritional requirement of pre-weaned dairy calves.

Post-Weaning (Pre-Puberty-Parturition)

In contrast to pre-weaned calves, higher concentrations of protein and energy for pre-pubertal heifers resulted in decreased milk production. Zanton et al. determined that the optimal growth rate of prepubertal Holstein heifers is 800 g/day by summarizing literature on prepubertal average daily gain rates and first lactation milk and protein yield (Zanton et al., 2007). To maximize lactation performance, it is recommended that heifers calve at 22.5-23.5 months of age (Lammers et al., 1999). For this to occur, heifers should reach puberty at 11-13 months and be bred at 13-15 months (Lammers et al., 1999). Accelerated growth programs have been examined in attempt to reduce the age or puberty.

In a study by Lammers et al. (1999), heifers were reared to achieve growth rates of 1000 g/day or 700g/day, with or without estrogen. Feed efficiency increased by 2.4 percent with estrogen implants and by 5.1 percent for growth rate of 1000g/d compared to controls. Fat -corrected milk (FCM) yield during the first lactation was decreased by 5.2 percent for estrogen and by 7.1 percent for accelerated growth (Lammers et al., 1999). The estrogen implant delayed puberty (Lammers et al. 1999), whereas the milk yield, and milk fat and protein yield were reduced by the accelerated growth program (Lammers et al., 1999). Holstein heifers (starting body weight of 126 kg) with a growth rate of 1200 g/ day were taller through the wither s and had greater mammary fat compared to heifers grown at 800 g/ day (Radcliffe et al., 1997).

A similar study by Hoffman et al. (1996) examined an accelerated growth program along with early and delayed breeding in postpubertal heifers to increase first lactation milk yield. Accelerated growth caused earlier calving for body weight, smaller wither heigh, smaller hip width, and smaller postpartum body weight (Hoffman et al., 1996). In delayed breeding groups, heifers were taller with a greater body condition score and had a greater incidence of dystocia. No effects on lactation were noted with delayed breeding groups. (Hoffman et al., 1996). In contrast, early breeding minimized incidence of dystocia, but resulted in lower milk yields during first lactation (Hoffman et al., 1996).

Another approach is to reduce production costs of replacement animals is to utilize restriction feeding. Bred heifers fed on a limit regimen displayed a 30% feed efficiency improvement (Khan et al., 2008). This feeding system has been used successfully with beef cattle and ewes (Hoffman, 2008). Dairy heifer vocalization was greater for one week following the transition to limit feeding. This approach requires adequate bunk space for all heifers in that heifers fed at 80% of ad libitum intake will consume all food within one hour (Khan et al., 2008)), and inedible bedding (Khan et al., 2008). Minor behavior issues among heifers were observed, but no quantified (Hoffman, 2008). Prior to implementation of restricted feeding, diets must be formulated to manage average daily gain (Zanton et al., 2007). Limit feeding high concentrate diets reduced manure excretion and decreased feed use and cost without appearing to adversely affect performance (Hoffman, 2008).

Tools for Analysis

Breed-Specific Growth Charts

Established breed growth curves from data collected from 5723 heifers of 163 commercial Holsetin herds from 1983 to 1985 (Heinrichs and Hargrove, 1987) and 1564 heifers of 49 commercial Jersey herds from 1984-1987 (Heinrichs and Hargrove, 1991) were used to create these growth models. Means for height and weight of each breed at each age (1-24 months), were used to describe their relationship with age by regression analyses for Holsteins (Heinrichs and Hargrove, 1987) and Jerseys (Heinrichs and Hargrove, 1991). From the means, a regression line was created (Heinrichs and Hargrove, 1987 and 1991). The process was repeated using a subset of the data one standard deviation above and below the mean (Heinrichs and Hargrove, 1987 and 1991). The resulting 3rd order regressions for height,cm and weight, kg relative to age of heifer, mo are displayed in **Table 1.**

Table 1

Breed	Dependant Variables	Intercept	Regression Coefficients of the Independent Variable (Age, mo)		
			Linear	Quadratic	Cubic
Holstein	Wt. Mean, kg	40.274	19.870	.285	-.0119
Holstein	Wt. Mean +1 SD_1,kg	4.461	23.779	.237	-.0120
Holstein	Ht. Mean, cm	75.413	5.153	-.158	.00177
Holstein	Ht. Mean + 1 SD, cm	78.767	5.733	-.203	.00279
Jersey	Wt. Mean, kg	22.122	16.685	-.047	-.0027
Jersey	Wt. Mean + 1 SD, kg	24.620	21.239	-.246	-.0015
Jersey	Ht. Mean, cm	68.496	4.982	-.191	.0031
Jersey	Ht. Mean + 1 SD, cm	73.819	5.093	-.202	.0033

Regression Equations of Growth Models based on age for Self-Input Spreadsheets for Holsteins (Heinrichs and Hargrove, 1987) and Jerseys (Heinrichs and Hargrove, 1991).
[1] SD = Standard Deviation

Other breeds with breed-specific growth charts available include Guernsey, Ayrshire, Milking Shorthorn, and Brown Swiss (Jones and Heinrichs, 2002). Heifers of the data set were observed to be larger in the prepubertal period than previously measured (Heinrichs and Hargrove, 1987). This was attributed to increased because of artificial insemination allowing for selection of larger framed animals (Heinrichs and Hargrove, 1987).

Currently, commercially available self-input spreadsheets for monitoring heifer growth are available through Pennsylvania State University (Penn State) extension (Jones and Heinrichs, 2002). This tool has been developed by Penn State extension for producers to use as a benchmark (Jones and Heinrichs, 2002). Monitoring can involve either a single, comprehensive survey of her status or multiple testing dates and tracking of herd changes. In these spreadsheets, height and weight are used independent of one another to track growth.

Mature Body Weight Calculation

Another on-farm monitor of heifer programs calculates the percent of mature body weight of a heifer at specific ages. The mature body weight is estimated from the dam's body weight 0-21 days post-calving adjusted to represent the 4^{th} lactation. As an on farm tool, it can be used to determine the optimum weight at breeding and calving, as a percent of mature body weight (Khan et al., 2008). While this may be the most accurate predictor of individual growth in a single environment, it may not be appropriate for the entire herd (Khan et al., 2008). Crossbreed adjustments can be made to compensate for a sire of a different breed (Khan et al., 2008), by accounting for genetic differences in size between sire and dam associated with each breed. This concept introduces a beef-type growth model into dairy programs. A beef growth model from the 1996 NRC that accounted for age, current body weight, and targeted mature body weight was adjusted to predict dairy heifer weight and nutritional requirements (Fox et al., 1999). This method uses weight at critical points such as first calving relative to mature body weight to determine a recommendation for average daily gain (Fox et al., 1999). While it appears to predict accurately, it is limited by accounting only for weight and inherent breed differences in structure; neither height nor body condition is measured. It has not been tested for animals weighing less than 100 kg (Fox et al., 1999), and the method appears to be limited by a small number of time points (breeding and parturition) to track development.

Objective

The purpose of this study was to evaluate the Penn State growth models for Holstein and Jersey heifers (Table 1) utilizing actual measurements from the Oregon State University dairy. Genetic and management improvements may have altered heifer growth patterns significantly enough that the Penn State growth models are no longer accurately describe current populations. Because use of such models is recommended for herd monitoring, they must be accurate and useful predictors. To determine the predictive abilities of the Penn State models in contemporary populations, the observed data was used to determine linear and mean biases.

Materials and Methods

OSU Herd Description

The Holstein heifers included 53 animals ranging in age from 17 days to 27 months, and representing six sires. Twenty-five heifers were sired by 29HO9023 and 14 heifers were sired by 11H8342. The Jersey heifers included 45 animals ranging in age from 4 days to 24 months, and represented twelve sires. Thirteen heifers were sired by 122J5181 and 11 heifers were sired by 7J590.

Heifers were comingled amongst breed and were arranged in management groups according to age and reproductive status. Eleven heifers, age 0-2 months, were in hutches. Thirty heifers, age 3-11 months, were in the pre-puberty heifer barn. Eighteen heifers, age 7-18 months, were in the breeding barn. The remaining 39 bred heifers were in two groups housed in freestalls: 24 bred heifers, age 12-23 months, were in the dry-cow barn, and 15 bred heifers, age 15-27 months were in the main barn. Sire representation within management groups is demonstrated in **Table 2.**

Table 2

Sire	Hutches	Pre-Puberty	Breeding	Dry	Main
7H5841	0	3	2	0	0
11H8342	8	5	1	0	0
29H9023	0	5	2	8	10
200H44	0	0	1	0	2
200H7030	0	0	1	4	0
200H8410	0	0	0	1	0
7J254	0	0	2	0	0
7J290	0	3	1	0	0
7J329	0	2	0	0	0
7J535	0	1	0	3	0
7J590	0	0	3	5	3
7J696	0	1	1	0	0
7J510	1	0	0	0	0
7J696	0	1	0	0	0
11J725	0	0	0	2	0
122J5181	0	9	4	0	0
200J303	0	0	0	1	0
200J989	2	0	0	0	0

Sire Representation by Management Group

Data Collection

Animals were measured one time within two consecutive days. Hip heights were measured using and altitude stick with a level on the crossbar for accuracy, and adjusted to the nearest ¼ inch to account for slope of the floor. Weights were measured using one of two electronic scales appropriate for animal size.

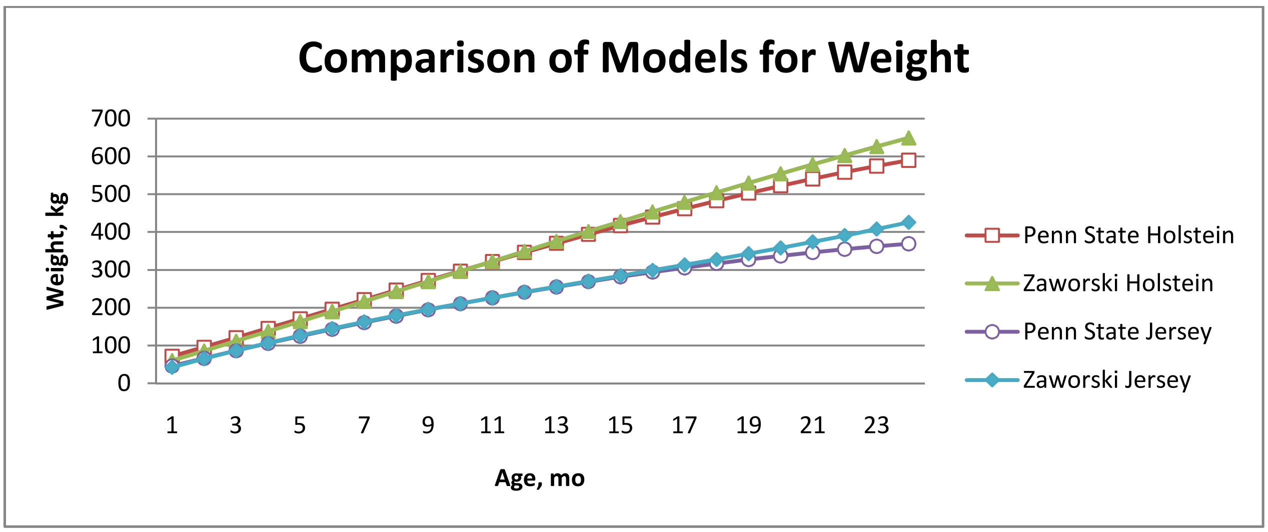
Analysis

Predicted weight and height values for each animal were calculated using the Penn State equations. New regression equations were then created in SAS (PROC REG procedures, SAS 2007) to fit the observed data for height and weight within each breed. The new regression equations (Zaworski models) were then visually compared to the Penn State models for mean populations and for populations one standard deviation above the mean. All Penn State models under-predicted, so the models for one standard deviation above then mean were used exclusively for further testing. A simple T-test of residual values calculated from the observed data and the Penn State models determined the statistical significance of the variance. SAS PROC MIXED procedures were then used to evaluate breed effects and sire effects on the residuals (SAS, 2007). Finally, the methodology of Norman St-Pierre, (2001) was used to evaluate mean and linear biases of the model.

Results/ Discussion

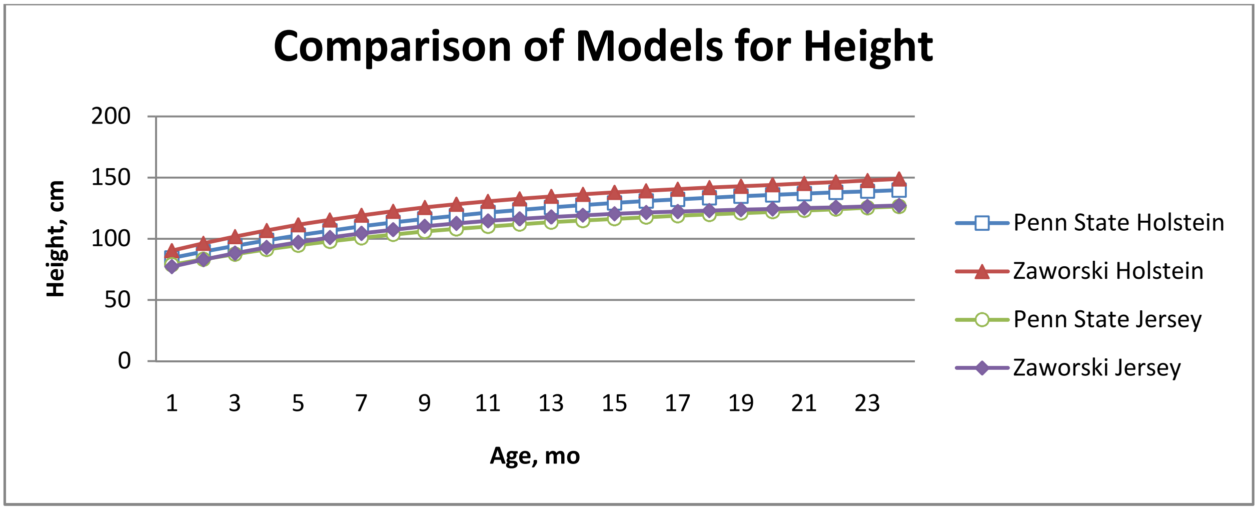
Predicted height and weight values were calculated based on age using the Penn State equations for Holsteins (Heinrichs and Hargrove, 1987) and Jerseys (Heinrichs and Hargrove, 1991). New regression equations were created in SAS to fit the observed data for height and weight within each breed. These new regression equations were then compared with the Penn State equations for one standard deviation above the mean, as shown in **Figures 1 & 2**.

Figure 1



Comparison of predicted weights by age. Penn State equations are from the Penn State models, Zaworski equations were calculated using SAS PROC REG to fit the OSU data.

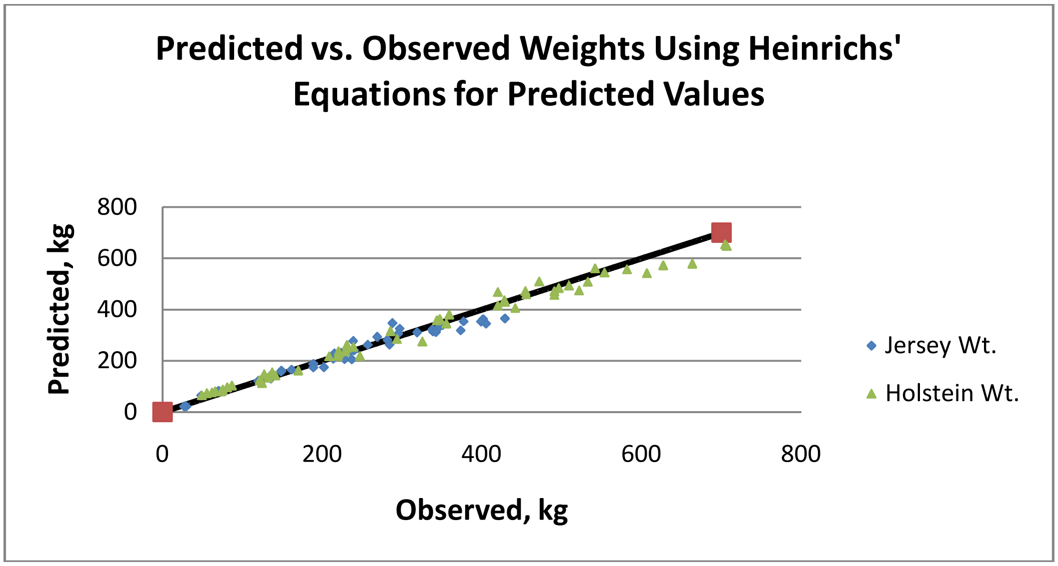
Figure 2



Comparison of predicted heights by age. Penn State equations are from the Penn State models, Zaworski equations were calculated using SAS PROC REG to fit the OSU data.

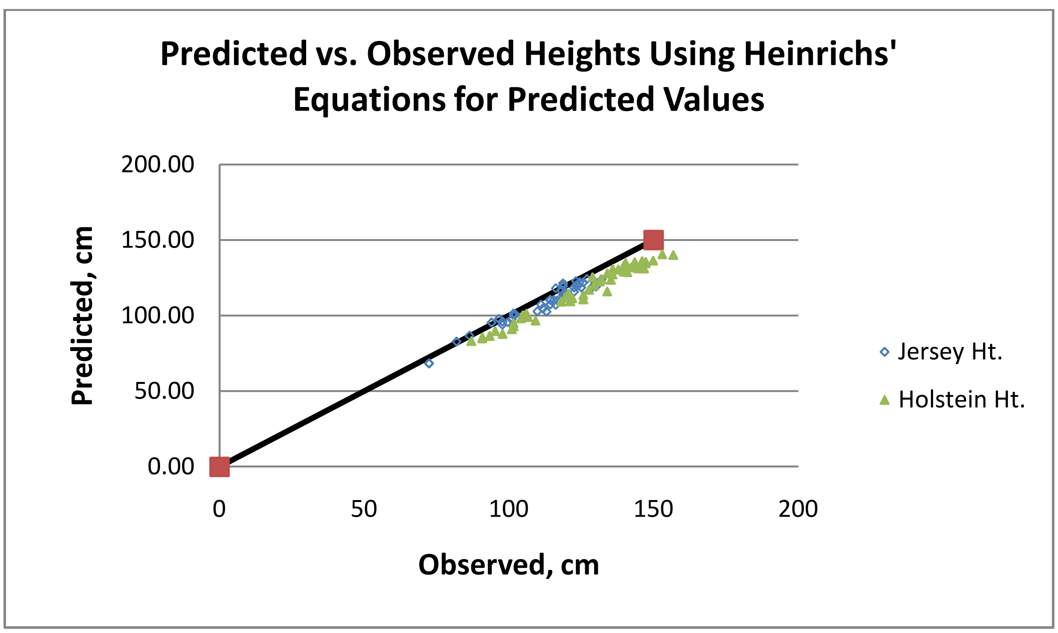
Values predicted with the Penn State equations were regressed against observed values to create graphs for demonstration of the accuracy of the predictions, **Figures 3 & 4**. In a perfectly predicting model, all points fall along the reference line of y = x.

Figure 3



Comparison of predicted vs. observed values for weight using the Penn State models against a y= x reference line.

Figure 4



Comparison of predicted vs. observed values for height using the Penn State models against a y=x reference line.

Next, residual values (Predicted- Observed) of the Penn State models were calculated. A T-test was then performed in SAS on all residual values for each measurement within breed. The sum of residuals was significantly different from the null hypothesis (H_0: Sum of residuals = 0) as shown in **Table 3**. This indicated a significant bias from on the prediction from the Penn State models for both height and weight of both breeds.

Table 3

Residuals	T-test	P-value
Holstein Wt.	-7.86302	<.0001
Holstein Ht.	-28.1649	<.0001
Jersey Wt.	-8.07753	<.0001
Jersey Ht.	-16.5381	<.0001

Significance of variance from the Penn State models.
Residuals = Predicted - Observed. H_0: Sum of Residuals = 0

SAS PROC MIXED was then used to determine the sire effect and breed effect on the residual values. The significance is shown in **Table 4,** where a strong effect of breed and sire on height can be noted, with a smaller influence on weight.

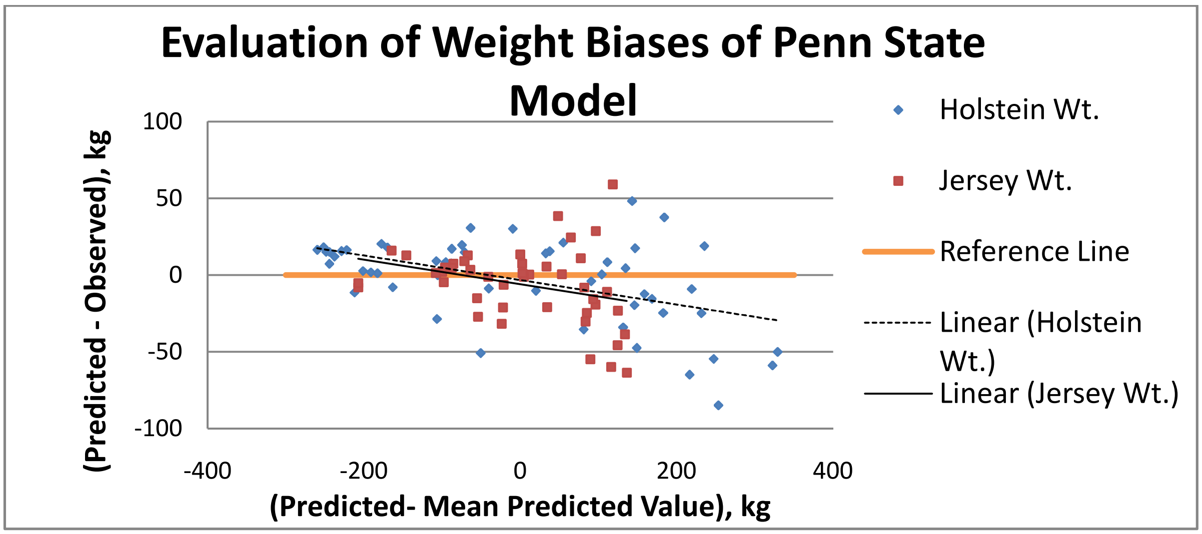
Table 4

Effect	F-values	Pr > F
Sire		
Model for Weight	1.87	0.0425
Model for Height	7.84	<.0001
Breed		
Model for Weight	4.05	0.0473
Model for Height	53.98	<.0001

Significance of sire effect and breed effect on residual values. Residual values were calculated using the Penn State models to determine predicted values.

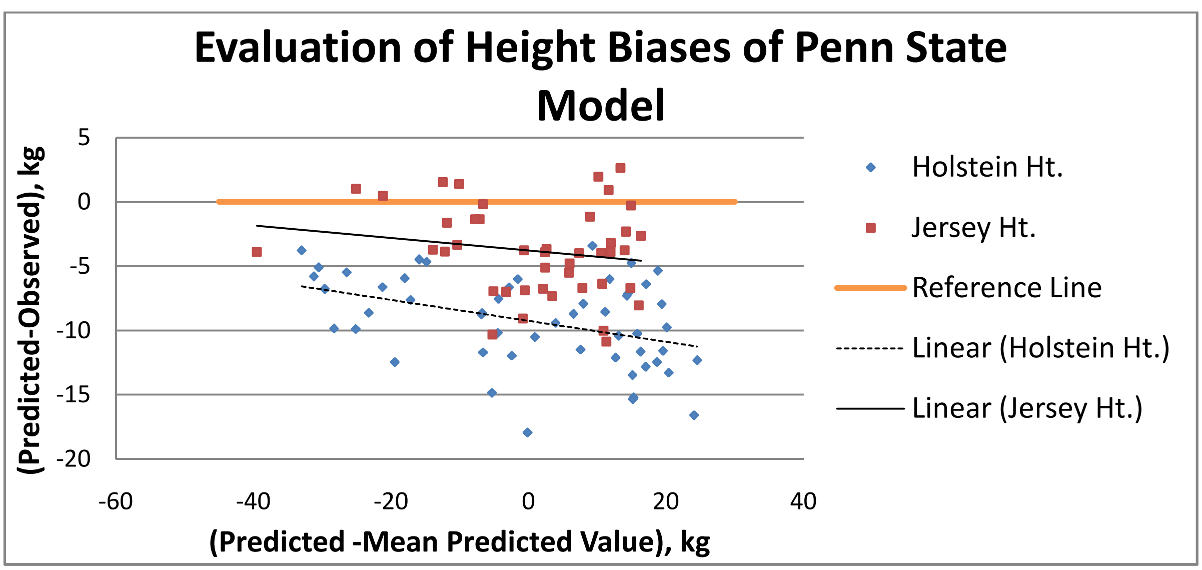
Next, SAS PROC MEANS was used to determine the mean of the predicted values. In order to evaluate biases, predictions were centered to make the slopes and intercepts independent. Residuals were then regressed in SAS (PROC REG) against the mean-centered prediction (predicted value- mean of predicted values). Methods presented by Norman St-Pierre (St-Pierre, 2003) were used to determine the mean-centered biases. Results are displayed in **Figure 5, Figure 6, and Table 5.**

Figure 5



Regression of residuals vs. mean-centered predictions (determined by Penn State models) for weight.

Figure 6



Regression of residuals vs. mean-centered predictions (determined by Penn State models) for height.

The regression equation of mean-centered predictions,

$\mathbf{e_i = b_0 + b_1 (MN_i - MN) + \check{e}_i}$ (St-Pierre, 2003) , demonstrates both linear and mean biases, where:

$\mathbf{e_i}$ = ith residual value

$\mathbf{b_0}$ = fixed effect (intercept) = mean bias

$\mathbf{b_1}$ = fixed effect (slope) = linear bias

$\mathbf{MN_i}$ = ith predicted value of measurement (height or weight)

MN = mean of all predicted values of measurement (height or weight)

$\mathbf{\check{e}_i}$ = error of the regression of residuals on predicted values

Using this equation, the mean and linear biases of the Penn State models were determined (**Table 5)**. To determine the significance of the biases, the absolute value of the maximum bias was compared to the standard error, in all cases the maximum bias exceeded the standard error, indicating a significant error.

Table 5

Summary of Mean-Centered Bias Regressions				
	Mean Bias	Linear Bias	Max. Bias	Standard Error
Holstein Weight	-14.96	-0.1	-31.72 kg	24.6 kg
Jersey Weight	-33.9	-0.12	-49.02 kg	22.5 kg
Holstein Height	-5.4	-0.08	-17.46 cm	3.3 cm
Jersey Height	-9.34	-0.07	-10.32 cm	3.5 cm

Regression equations for prediction biases of the Penn State models, where slope = linear bias and intercept = mean bias. All P values were ≤ 0.01. Bias is significant for all values: |Max. Bias| > Standard Error. Model is beyond standard error.

The mean and linear biases of the graph demonstrate the insufficiencies of the Penn State model as a predictor of growth and development for the OSU dairy heifer population.

Without further study of a larger population, it cannot be determined whether the differences between the models and the data are a result of the models themselves, or whether the OSU herd offers an extreme population. Within the OSU herd, there is limited sire representation, and sire was determined to affect the residual values. Nationwide growth and development trends cannot be verified without a much larger sample size. However, the results using this small population size were strong enough to recommend caution of using the Penn State models as an exclusive guide for growth.

Once optimum growth rates for each production stage phase of growth in management groups have been determined, a beef-type model using mature body weights to predict weight at a given age may be more beneficial and adaptable for contemporary populations.

Conclusion

Much research is currently being done to maximize lifetime milk production and minimize rearing costs of dairy heifers. While self-input spreadsheets have the potential to serve as a useful tool for producers to monitor heifer programs, the current models may not perform well with current genetics and management. As ideal rates of gain are determined, monitoring systems may shift towards beef-type models, using predicted mature body weight as a target rather than a breed standard. Ultimately, the goal is to develop heifers for maximum lactation potential at lowest cost. Any monitoring system should be used in conjunction with a visual appraisal of the body condition as current models are based almost exclusively on weight and height measurements. This study revealed the biases of the models through a T-test, the influence of both sire and breed on the overall biases of the models, and the mean and linear biases of the models. Regardless of the measurement (height or weight), the Penn State models for one standard deviation above the mean under-predicted for both Holsteins and Jerseys.

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