Optimization of Dairy Heifer Management Decisions Based on Production Conditions of Pennsylvania

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ABSTRACT

We used a dynamic programming model to determine optimum rearing decisions of dairy replacements. Heifers were described in the model by age, season, body weight, pregnancy state, and prepubertal growth rate. Prices and parameters were chosen to represent the dairy population of Pennsylvania. We calculated monthly costs and revenues from calf value, feed costs, veterinary costs, semen costs, carcass value, and full-grown heifer value. The model considered a stochastic variation in the onset of puberty, conception, involuntary disposal, and a seasonal variation in the prices of calves, heifers, and feed.

Based on a critical prepubertal average daily gain of 0.9 kg/d and a maximum achievable postpubertal growth rate of 1.1 kg/d, the optimum practice resulted in an average age at first calving of 20.5 mo at a body weight of 563 kg. Discounted net returns equaled $107 per heifer per year. The optimum rearing practice was not sensitive to seasonal variation in prices. Nevertheless, the economic results per season of birth varied considerably; the highest income per heifer was obtained from heifers born in December ($142/yr), whereas those born in May yielded the lowest ($100/yr).

Sensitivity analyses demonstrated a considerable influence of growth rate restrictions and variation in reproductive performance on both the optimal rearing practices as the expected net returns.

(Key words: heifer rearing, dynamic programming, optimization, Pennsylvania)

Abbreviation key: ADG = average daily gain, CPM = Cornell Penn Miner dairy system, NDHEP = National Dairy Heifer Evaluation Project.

INTRODUCTION

Most investigators agree that the average age of dairy heifers at first calving should be 24 mo or less (7, 9). In 1994, the average age at first calving for Pennsylvania Holsteins on DHI was 25.9 mo, compared with 26.9 mo in 1985. Although still above the recommended calving age, average calving age has tremendously improved during the last 10 yr (6).

Research efforts have historically been designed under the hypothesis that a single optimal age at first calving exists. While this assumption might be true for a given set of conditions, a more global approach would be to understand the underlying dynamic economic aspects of the process. A specified distribution of ages at calving might offer greater economic reward than maintaining a mean age of first calving.

A farmer exercises control over his rearing unit in two main areas: a nutritional plane of growth and insemination age. These two management controls interact with biological aspects of growth, thereby influencing future profitability of the dairy heifer (9). A thorough understanding of these biological interactions is still lacking (9, 14). A model that represents heifer management decisions and their potential impacts would, therefore, be a suitable alternative for evaluating the technical and economic consequences of various rearing strategies.

Mourits et al. (16) presented a stochastic dynamic programming model to optimize the dairy heifer rearing strategy under Dutch conditions. Net returns per heifer place per year and optimum calving age and weight were tested for sensitivity to changes in model parameters (15). Results showed that optimal rearing is mainly sensitive to changes in production parameters, whereas the influences of changes in price parameters are negligible.

Dutch dairy production systems differ considerably from those in the United States in relatively higher beef prices, milk prices, and feed costs. Feeding regimens and management systems differ as well; within
the Dutch production system fresh feeds (pasturing) are used more extensively and TMR less (23).

The objective of this study was to adapt the rearing model of Mourits et al. (15, 16) to rearing conditions of the United States (Pennsylvania). The application of the adapted model was demonstrated by evaluating a scenario standard for a typical Pennsylvania dairy herd. Furthermore, analyses were carried out to provide information on the sensitivity of optimum rearing practices to changes in production variables like growth rate restrictions and reproductive performance.

**MATERIALS AND METHODS**

**Heifer Rearing Model**

In the stochastic dynamic optimization model of Mourits et al. (16), heifer rearing is modeled as a separate farming activity. Optimization starts with newborn calves and ends with full-grown heifers to be sold at market prices. The heifer-rearing model is established to make monthly rearing decisions that lead to the maximum expected present value of net returns per heifer place. Mourits et al. (16) provide a detailed description of the dynamic optimization model and its variables.

To represent the Pennsylvania dairy population, the model parameters were adjusted to the Pennsylvania production conditions (6, 7, 13, 19, 20). Prices within the model were mainly based on data from the Pennsylvania Agricultural Statistics Service (19, 20) and the Livestock Reporter, Lancaster, Pennsylvania (13). To determine some general management input factors (i.e., average age at weaning), we used Northeast regional data from the US National Animal Health Monitoring System 1991–1992 National Dairy Heifer Evaluation Project (NDHEP) (8, 25, 26).

**Stages, States, Decisions, and Transitions**

In the Pennsylvania heifer-rearing model, a fixed weaning period was considered, resulting in weaned calves at 2 mo of age and a BW of 75 kg. Optimization of the monthly decisions therefore started when the calves were 2 mo old. The maximum duration of the rearing period was set at 30 mo, resulting in 29 decision stages (2, 3, ..., 30 mo). Within the model, the state of a heifer was described by the state variables age (29 classes), season (12 classes), BW (173 classes), reproduction state (32 classes), and maximum prepubertal growth rate (three classes). Season was considered due to its effects on prices of feed, milk, meat, and calves and on the expected milk production, which can substantially influence economic results. Body weight was the main variable, because it determined the onset of puberty and influenced feed costs, slaughter value, expected milk production, and market price. The reproductive state described the various prepubertal, cyclic, and pregnancy states, while the maximum prepubertal growth rate variable was included to estimate the influence of the prepubertal average daily gain (ADG) on the future milk production ability (16). In this study, a prepubertal growth rate beyond the 0.9 kg/d was assumed to negatively influence the future production ability of the heifer (14, 27).

The model optimized decisions on growth rate, insemination, and replacement. The growth rate decision was split into five levels of growth rate, viz., 0.3, 0.5, 0.7, 0.9, and 1.1 kg/d. The last four growth-rate decisions could be made for all heifers with a reproduction state of less than 7 mo of pregnancy. During the last 2 mo of pregnancy, it was assumed that the only possible growth rate equaled 0.3 kg/d (fetal weight gain excluded). Insemination was defined as possible during the cyclic reproduction states, until 22 mo of age. Heifers that failed to conceive after 6 cyclic mo were replaced. The decision to replace resulted in an immediate replacement at the beginning of the month. Heifers that were 9 mo pregnant were automatically replaced (i.e., sold to the dairy herd).

Stochastic elements within the model included onset of puberty, conception, and involuntary disposal. The probability distribution of puberty over the BW classes was the same as that used in the Dutch version (16), described by an average BW of 276 kg and a variation coefficient of 10%.

The marginal probabilities of conception during each cyclic month were determined by the product of the percentage of estruses detected, the marginal conception rate per service, and number of estruses per month (16). Estrus detection rates in dairy herds are often low (<50%) and represent a major limiting factor in optimizing reproductive performance (22). In the Pennsylvania version of the model, the estrus detection rate was defined at 50%, while the conception rates were set at 35% for the first estrous cycle, at 40% for the second estrus, and at 50% for all subsequent estrous cycles.

According to the NDHEP results of 1991 to 1992 (26), 6.8% of the heifer calves within the Northeast region died before weaning, and 2.2% died between weaning and calving. Based on these average percentages, the probability of involuntary disposal during the weaning period was defined at 6%, while the postweaning probabilities of involuntary disposal per month of age were specified at 0.33, 0.22, and 0.11% for, respectively, mo 2 to 4 and at 0.08% for higher months.
Table 1: Base prices and other parameters used to determine the optimum rearing practices within a Pennsylvania dairy production system.

<table>
<thead>
<tr>
<th>Costs</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heifer calf, $</td>
<td>$114</td>
</tr>
<tr>
<td>Weaning period, $</td>
<td>$99</td>
</tr>
<tr>
<td>Veterinary costs, $/mo</td>
<td></td>
</tr>
<tr>
<td>age 2 to 5 mo</td>
<td>$8</td>
</tr>
<tr>
<td>age 6 to 12 mo</td>
<td>$6</td>
</tr>
<tr>
<td>age 13 to 30 mo</td>
<td>$5</td>
</tr>
<tr>
<td>Insemination, $</td>
<td>$12</td>
</tr>
<tr>
<td>Feed, (see Table 2)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Revenues</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Market value standard heifer, $</td>
<td>$1065</td>
</tr>
<tr>
<td>Milk price corrected for feed costs, $/kg</td>
<td>$0.26</td>
</tr>
<tr>
<td>Value slaughter cow, $/kg</td>
<td>$0.69</td>
</tr>
<tr>
<td>Characteristics standard heifer</td>
<td></td>
</tr>
<tr>
<td>Critical prepubertal rate, kg/d</td>
<td>0.9</td>
</tr>
<tr>
<td>Body weight at calving, kg</td>
<td>525</td>
</tr>
<tr>
<td>305-d milk production, kg</td>
<td>6800</td>
</tr>
<tr>
<td>Others</td>
<td></td>
</tr>
<tr>
<td>Annual real interest rate, %</td>
<td>4</td>
</tr>
</tbody>
</table>

1Livestock Reporter (13).
2Heinrichs (6).
3Pennsylvania Agricultural Statistics Service (19).
4Pennsylvania Agricultural Statistics Service (20).
5Heinrichs and Vazquez-Anon (7).
6US Department of Agriculture (25).

Economic Components

The base price and parameters used in the model to represent the dairy production circumstances of Pennsylvania are shown in Table 1.

Costs. The costs within the model included the costs of heifer calves, insemination, veterinary treatment, and feed costs. The basic price of $114 per heifer calf was based on the average market price for Holstein heifer calves in Pennsylvania within the BW range of 39 to 55 kg (13). Due to seasonal variation, calf costs varied from $78 for calves born in July to $133 for calves born in May, as represented by Figure 1.

The variable costs of the weaning period were set at $99/heifer, while insemination costs equaled $12. Veterinary costs varied from $8/mo during the first 6 mo of rearing to $5/mo during the second year of rearing.

Feed costs represent the largest cost associated with heifer rearing. In the Pennsylvania heifer-rearing model, monthly least cost rations were formulated with the CPM (Cornell Penn Miner) dairy system (CPM) (2). Dietary nutrient requirements were calculated as energy and protein requirements specified by CPM according to season, BW, growth, and gestation. The mean of the initial and final weight of each month was used to calculate the average energy and protein requirements per month of age. Based on the included feed dictionary (Table 2), the CPM model balanced the provision of nutrients in the diet against the requirements of the animal. Environmental factors such as temperature, hair depth, and night cooling (Table 3) were defined per season to account for the environmental influence on maintenance requirements and DMI (4, 18). Seasonal variation in prices of feed was only considered for the generally applied ingredients, i.e., corn grain and soybean meal (Table 2).

In decision-making, only variable costs should be considered because fixed costs remain the same regardless of the choices made (1, 11). The heifer-rearing model focuses on the optimization of operational (short-term) and tactical decisions (medium-term). Strategic (long-term) decisions like building a new housing system or hiring additional manpower are not considered. Consequently, the costs of housing and labor are considered fixed and were not included within the model calculations (1, 11).

Revenues. The market value of full-grown heifers was estimated relatively to a predefined standard heifer by a system of premiums (16). To define a standard heifer, we used the characteristics of an average Pennsylvania heifer (Table 1). The premiums were based on the calving season because of its influence on production and prices (14), the BW at calving due to its relation with milk production (9, 27), and the prepubertal ADG for its expected impact on future production (3).

The market price of an average Holstein replacement heifer equaled $1065 (13). The premium of calving season was based on the seasonal differences in market price (Figure 1). Highest market price was achieved in October ($1138), and the lowest price in February ($1011).

Pennsylvania DHI first-lactation data of 1990 showed an average BW at calving of 513 kg (7), while the results of NDHEP (25) reported an average BW of 530 kg for Holstein heifers at an age of 24 mo. Therefore, we set...
standard BW at calving at an average of 525 kg (Table 1). In the model, heifers with a BW of 1 kg above (or below) the standard weight of 525 kg were expected to produce 0.1% more (or less) than the predefined standard milk production. This relation is defined linear for BW < 570 kg (16).

In this study, prepubertal growth rates beyond the critical prepubertal rate of 0.9 kg/d had a negative influence on the future production ability of the heifer. For instance, a maximum prepubertal rate of 1.1 kg/d was expected to depress the milk production ability by 4.9% (16).

The premiums reflecting the impact of BW at calving and the influence of maximum prepubertal growth rate were determined by the difference between the expected milk production and the standard production (= 6800 kg; Table 1) multiplied by the milk price corrected for feed costs (= $0.26/kg; Table 1). For instance, a heifer with a calving weight of 550 kg had an expected production of 6800 kg * [1 + 0.001 kg milk/kg BW] = 6970 kg. If the maximum prepubertal rearing rate corresponded to 1.1 kg/d, future production ability was depressed by 4.9%. Hence, the premium of expected future milk production was equal to (0.951 * 6970 kg - 6800 kg) * $0.26/kg = $45. Subsequently, with February as calving month, the market value of the heifer corresponded to $1011 - $45 = $966. The market value of heifers less than 9 mo pregnant was set equal to the slaughter value (Table 1). No rearing was considered when heifers are culled involuntarily.

**Others.** The model accounted for time preference of costs and revenues by using a real annual interest rate of 4%.

**RESULTS**

**Standard Conditions: Economic and Technical Results**

Based on the described input variables, the heifer-rearing model yielded optimum decisions for all possible states of a heifer. Table 4 shows the average farm results after these decisions were applied.

The optimal rearing practices resulted in an average calving age of 20.5 mo at an average BW of 563 kg. Figure 2 displays the distribution of age at calving. Under the optimal strategy 60.2% of the heifers calved between the age of 19 and 22 mo. Only 6.0% had a calving age of equal to or older than 24 mo.

Most heifers were reared as full-grown dairy replacements (88.0%). Nevertheless, 10.2% of the postweaned heifers were sold as slaughter cows due to insufficient reproduction, i.e., heifers still open after 6 cyclic mo. Only 1.8% of the postweaned heifers were involuntarily culled (Table 4).

Under the optimum rearing practices, prepubertal heifers were reared at an ADG of 0.88 kg/d, resulting in an average age at puberty of 9.8 mo at a BW of 288 kg. Insemination commenced immediately after the onset of puberty. During the second year, heifers were reared at higher gain rates (0.97 kg/d on average) to achieve the optimum calving weight, ending with the predefined 0.3 kg/d growth during the last 2 mo of gestation.

The optimum rearing pattern of dairy replacements resulted in an average DMI per weaned heifer per year of 3276 kg. Average DMI consisted mainly of corn silage (51.7%), alfalfa silage (21.4%), and oat straw (20.3%).

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**Table 3. Environmental factors per season.**

<table>
<thead>
<tr>
<th>Temperature1 (F)</th>
<th>Hair depth (cm)</th>
<th>Night cooling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan–Mar</td>
<td>35.3</td>
<td>1.3</td>
</tr>
<tr>
<td>Apr–Jun</td>
<td>62.3</td>
<td>0.9</td>
</tr>
<tr>
<td>Jul–Sep</td>
<td>73.5</td>
<td>0.5</td>
</tr>
<tr>
<td>Oct–Dec</td>
<td>46.1</td>
<td>0.9</td>
</tr>
</tbody>
</table>

1Temperature reflects the average seasonal temperature based on the temperature measured in Philadelphia during the period of 1961 to 1990 (17).
Table 4. Average rearing results per alternative.

<table>
<thead>
<tr>
<th></th>
<th>Basic¹</th>
<th>Pre²</th>
<th>Post³</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average age at puberty, mo</td>
<td>9.8</td>
<td>11.9</td>
<td>9.8</td>
</tr>
<tr>
<td>Average calving age, mo</td>
<td>20.5</td>
<td>22.6</td>
<td>20.6</td>
</tr>
<tr>
<td>Average calving weight, kg</td>
<td>563</td>
<td>563</td>
<td>519</td>
</tr>
<tr>
<td>% culled involuntarily</td>
<td>1.8</td>
<td>2.1</td>
<td>1.8</td>
</tr>
<tr>
<td>% reared as dairy replacements</td>
<td>88.0</td>
<td>87.8</td>
<td>87.7</td>
</tr>
<tr>
<td>% sold as slaughter cows</td>
<td>10.2</td>
<td>10.1</td>
<td>10.5</td>
</tr>
<tr>
<td>Discounted net returns, $/yr per heifer</td>
<td>125</td>
<td>91</td>
<td>81</td>
</tr>
<tr>
<td>Discounted rearing costs, $/yr per heifer</td>
<td>462</td>
<td>438</td>
<td>464</td>
</tr>
<tr>
<td>Discounted feed costs, $/yr per heifer</td>
<td>239</td>
<td>230</td>
<td>242</td>
</tr>
</tbody>
</table>

¹Basic: critical prepubertal rate 0.9 kg/d, maximum rate postpubertal 1.1 kg/d.
²Pre: critical prepubertal rate 0.7 kg/d, maximum postpubertal rate 1.1 kg/d.
³Post: critical prepubertal rate 0.9 kg/d, maximum postpubertal rate 0.7 kg/d.

Figure 3 displays the composition of the formulated rations over time. The formation of the rations varied with age, due to the development of the ruminal system and altered nutritional requirements. The percentage of corn silage within the DMI increased from 13.2% during the interval of 2 to 4 mo of age to 65.6% within the age period of 14 to 16 mo. The contributions of alfalfa silage and corn grain displayed an opposite alteration; over the same period of time, the percentages of alfalfa silage and corn grain decreased from 41.4 and 18.3% to 14.8 and 1.4%, respectively. The strong alteration of the ration composition during the last rearing month resulted from the increased nutritional requirements during the last month of pregnancy.

The average discounted rearing costs were $462 per heifer per year, of which $239 (51.7%) was the average feed costs of weaned heifers. The expected net returns per heifer per year, calculated as an annuity, equaled $125 (Table 4).

Optimal rearing practices was not sensitive to season of birth, despite the seasonal differences in prices of calves, feed, and dairy replacements. Under the same optimum practices, discounted rearing costs were highest for birth month May ($474/yr) and lowest for birth month July ($438/yr). Seasonal differences in discounted feed costs were negligible; maximum difference between birth month was only $1 per heifer per year. The highest income per heifer was obtained from heifers born in December ($142), whereas those born in May yielded the lowest ($100), implying a difference of $42/yr.

Influence of Growth Rates Restrictions

Prepubertal growth rate. High levels of feeding that result in high prepubertal growth rates can severely reduce potential milk production. This reduction has been demonstrated in many experiments (3, 12, 21, 24, 27). In the Pennsylvania heifer model, future milk production ability was depressed when the prepubertal rearing rate exceeded 0.9 kg/d. This assumption corresponds with the results of Kertz et al. (12) and Van Amburgh et al. (27). However, Foldager and Sejrsen (3), Peri et al. (21), and Sejrsen and Purup (24) conclude that the critical upper limit of the prepubertal gain rate...
in large dairy breeds is already reached at a growth rate of 0.7 kg/d. This controversy demonstrates the incompleteness of our knowledge on the effect of nutrition on the milk production potential of heifers (16).

To study the impact of a lower critical prepubertal growth rate, we determined the optimum practices for the alternate situation in which the critical prepubertal rate was defined at 0.7 kg/d. Optimum rearing decisions resulted in an average age at puberty of 11.9 mo. Average calving age increased from 20.5 mo to 22.6 mo under standard conditions. The percentage of heifers with a calving age of 24 mo or higher increased to 30.6%.

Compared with the economic results under the standard conditions, average rearing costs were $24 per heifer per year lower. However, annual revenues were also decreased, resulting in reduced net returns of $91 per heifer per year.

Postpubertal growth rate. Body weight gain can be divided into an increase in structural tissue and in fat deposition. Structural growth starts slowly, reaches a maximum at puberty, and slows down thereafter (10). Besides an increase in fat deposition with developmental stage, higher energy diets also result in a proportionally higher fat deposition. Because of the lack of information on the composition of BW gain, we formulated the least-cost rations within the model on the assumption of an average BCS. We do not know to what extent this assumption can be extrapolated to a postpubertal growth pattern with growth rates of more than 0.8 kg/d.

To demonstrate the impact of a more moderate growth during the postpubertal period, we limited ADG after 3 reproductive (cyclic) mo to a maximum of 0.7 kg/d. Under such a gain restriction, optimal rearing decisions resulted in an average age of 20.6 mo at an average BW of 519 kg. Average rearing period was not extended, despite the limited postpubertal growth. As a consequence, at calving BW was 44 kg less than under the standard conditions and discounted net returns per year were reduced by $44 per heifer per year.

Influence of Reproductive Performance

Estrus detection rate. Under the standard conditions, a strikingly high percentage of heifers were culled due to insufficient reproduction (10.2%). To investigate the influence of reproductive performance, we varied the estrus detection rate 50% relative to that under standard conditions. Results obtained from this analysis are summarized in Table 5 and Figure 2.

The optimum practices based on an improved estrus detection rate of 75% resulted in an average calving age of 20.1 mo at a BW of 560 kg. As reflected by Figure 2, the skewness toward older calving ages decreased in comparison with the distribution of calving age under standard conditions. The percentage of heifers replaced for insufficient reproduction reduced to 2.5%. Discounted net returns per heifer per year were therefore $39 higher than in the standard conditions.

In cases in which the decreased detection rate of 25%, optimum practices resulted in an average calving age of 21.0 mo at a BW of 569 kg (Table 5). Due to the lower detection rate, skewness toward older calving ages increased (Figure 2). More than a third (34.1%) of the heifers were unable to conceive within a period of 6 cyclic mo and were therefore voluntarily replaced. This high percentage of premature replacement resulted in a shorter average raising period per heifer, explaining the somewhat reduced percentage of involuntarily culling (Table 5). Net returns were decreased to an amount of $29 per heifer per year.

Seasonal influence on reproductive performance. Climatic conditions as high temperature and humidity have a negative impact on reproductive performance (5). In this study, however, reproductive performance was assumed to be independent of seasonal influences, due to insufficient quantitative information on the seasonal variation in detection rate and conception rates. This partly explains the insensitivity of the optimum practices for season of birth under standard conditions.

To study the influence of seasonal variation in reproductive performance, we defined four multiplicative adjustment factors to reflect the average seasonal influence on detection rate and conception rates. These adjustment factors represented the months January through March, April through June, July through September, and October through December and were set at, respectively, 1.2, 1.0, 0.8, and 1.0.

The inclusion of seasonal variation in reproductive performance resulted in an average calving age of 20.5 mo (Table 5). Per season of birth average calving age varied from 20.3 to 20.8 mo, implying a maximum difference of only 2 wk. Distribution of age at puberty per season of birth was identical for all heifers. This result demonstrated that it was not profitable to extend the prepubertal period to prevent insemination during a less reproductive season.

The percentage of heifers replaced due to insufficient reproduction was highest for heifers born in July (13.4%) and lowest for heifers born in January (7.5%). Average net returns per heifer per year equaled $126 and varied per season of birth from $101 for heifers born in May to $152 for heifers born in January.

DISCUSSION

Results Pennsylvania Study

Based on the optimization results, we concluded that the optimal rearing patterns generally profited from
Table 5. Average rearing results per reproductive alternative.

<table>
<thead>
<tr>
<th></th>
<th>Basic¹</th>
<th>Det75²</th>
<th>Det25³</th>
<th>Season⁴</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average age at puberty, mo</td>
<td>9.8</td>
<td>9.8</td>
<td>9.8</td>
<td>9.8</td>
</tr>
<tr>
<td>Average calving age, mo</td>
<td>20.5</td>
<td>20.1</td>
<td>21.0</td>
<td>20.5</td>
</tr>
<tr>
<td>Average calving weight, kg</td>
<td>563</td>
<td>560</td>
<td>569</td>
<td>564</td>
</tr>
<tr>
<td>% involuntarily culled</td>
<td>1.8</td>
<td>1.9</td>
<td>1.8</td>
<td>1.9</td>
</tr>
<tr>
<td>% reared as dairy replacements</td>
<td>88.0</td>
<td>95.6</td>
<td>64.1</td>
<td>87.8</td>
</tr>
<tr>
<td>% sold as slaughter cows</td>
<td>10.2</td>
<td>2.5</td>
<td>34.1</td>
<td>10.3</td>
</tr>
<tr>
<td>Discounted net returns, $/yr per heifer</td>
<td>125</td>
<td>164</td>
<td>29</td>
<td>126</td>
</tr>
</tbody>
</table>

¹Basic: detection rate 50%, no seasonal variation in reproductive performance.
²Det75: detection rate 75%, no seasonal variation in reproductive performance.
³Det25: detection rate 25%, no seasonal variation in reproductive performance.
⁴Season: detection rate 50%, seasonal variation in reproductive performance.

limiting the prepubertal ADG to the critical prepubertal ADG because it prevented a decrease in future milk production capacity. The prepubertal phase was followed by a postpubertal compensatory feeding regime designed to capitalize on the positive effects on productivity of a heavier calving BW. However, little information is available on how compensatory feeding regimens alter BW gain composition (9). Further research on nutrient requirements for heifers with rapid rates of gain is, therefore, needed before we can recommend calving ages under 22 mo.

With the lack of exact information on fundamental elements of heifer rearing, the heifer-rearing model is a suitable alternative for evaluating the technical and economic consequences of various rearing strategies by means of sensitivity analyses.

In this study, these analyses were carried out to demonstrate the extent to which the optimum practices and economic results are influenced by limitations in growth. Defining the critical prepubertal ADG at 0.7 kg/d instead of 0.9 kg/d resulted in an increased average age at puberty and, indirectly, in an increased age at calving. Within the optimal rearing practices, the maximum prepubertal growth rate did not exceed the critical rate of 0.7 kg/d, demonstrating the significance of the expected negative impact of higher prepubertal growth rates. Higher rates would have reduced the rearing period and therefore the rearing costs, but these savings would not have compensated for the expected reduction in milk production. Compared with the results under standard conditions, the increase in rearing period of 2.1 mo resulted in a reduction in net returns of $34 per heifer per year (Table 4), i.e., $16/mo of increase in rearing period.

Heavier heifers have potentially higher milk revenues due to the positive relation between BW and first lactation. Therefore, an extension in rearing period by a delay in insemination could be profitable when postpubertal growth is limited (15). In this study, however, results of the restricted postpubertal ADG alternative indicated that the influence of BW on first lactation was of minor economic importance (Table 5). Despite the restriction, the average rearing period was comparable to the one within the standard conditions, resulting in a 44 kg lower average BW at calving. Consequently, average net returns reduced by $44 per heifer per year.

Differences in the economic results obtained by the sensitivity analyses on estrous detection rate emphasized the significance of an accurate heat detection system (Table 5). Variation in the estrous detection rate from 75 to 50% and from 50 to 25% demonstrated a reduction in net returns of $39 and $96 per heifer per year, respectively. Nevertheless, despite the alteration in detection rate average calving age remained within the range of 20 to 21 mo. Variation in average calving weight was even less; maximum difference in average BW equaled 9 kg (Table 5). These results demonstrate that the economic efficiency of a rearing practices can not be measured solely on characteristics as average calving age and average calving weight. Parameters describing the distribution of age at calving and the number of involuntarily and voluntarily replaced animals provide more relevant information.

Comparison of Pennsylvania and Dutch Models Study and Results

In the study of Mourits et al. (15, 16), the parameters of the model represented the Dutch Black and White dairy population (>90% Holstein). To represent the Pennsylvania dairy systems, we adjusted these model parameters to the Pennsylvania production circumstances (>90% Holstein), which especially concerned the economic variables. However, most of the biological characteristics remained valid.

The optimized rearing patterns within this study corresponded with the average results of the Dutch study.
Prepubertal growth rates below the critical rates were followed by highest rates achievable without detrimental effects. A striking difference between the results of both studies was the seasonal influence on optimal practices. In this Pennsylvania study, the seasonal influence on optimum practices was negligible. Under Dutch rearing conditions, optimum practices per month of birth considerably differed due to seasonal influence on prices and production. For instance, under the assumption of a critical prepubertal rate of 0.9 kg/d and a restricted postpubertal rate of 0.7 kg/d, average calving age per month of birth varied from 20.4 for birth heifers born in July to 22.2 mo for heifers born in November. The use of pasture was the main reason for the variation in rearing practices per month of birth. By the extension of the rearing period, November heifers reached a more profitable calving season, thereby profiting from the less expensive grazing season; additional revenues exceeded the cost of the extended rearing time. In the Pennsylvania alternative, a confinement feeding system is modeled resulting in the same optimum practices per season of birth. The differences in heifer market prices of subsequent calendar months were too small to compensate the extra rearing costs (mainly feed costs) of an extended rearing period to achieve a more profitable calving season.

Another noteworthy difference in the optimized rearing practices of both studies was the moment of first insemination. In the Pennsylvania study, insemination commenced immediately after the onset of puberty, while in the Dutch study, insemination was generally delayed. For instance, in the Dutch alternative based on a critical prepubertal rate of 0.9 kg/d and a limited postpubertal ADG of 0.7 kg/d, puberty occurred at an average age of 9.8 mo, while insemination commenced at an average age of 11.5 mo.

A possible explanation for this contrast was the differences in expected reproductive performance. The conception and detection rates in the Pennsylvania study were lower than in the Dutch study, resulting in a reduced reproductive performance. Because of this reduced reproductive performance and the assumption that open heifers are replaced after 6 cyclic mo, it could be economically more efficient to have heifers calving at an earlier age and lower weights than to extend the rearing period and have a decreased number of heifers (due to an increased replacement rate for insufficient reproduction) calving at higher weights. Nevertheless, an additional calculation based on an improved reproductive performance in the default Pennsylvania situation (detection and conception rates 95%) demonstrated that, despite the efficient reproduction, insemination still commenced immediately after puberty. Compared with the basic results, average age and weight at calving were reduced to 19.2 mo and 549 kg, respectively.

These results demonstrated that the differences between the Pennsylvania and the Dutch study at the time of first insemination was not the result of a difference in reproductive performance but a result of the difference in economic significance of an extra kilogram of BW at calving. As discussed earlier, an increase in BW at calving by an increase in rearing time was not optimal in the Pennsylvania case. However, this was opposite to the Dutch case in which additional revenues as a result of a heavier calving weight outweighed the extra costs of an extension in rearing time, resulting in higher average calving ages and weights.

CONCLUSION

Adapting the input variables of the heifer-rearing model of Mourits et al. (15, 16) made it possible to evaluate the influence of production variables on the optimum heifer-rearing strategy in a Pennsylvania production study. It was generally optimal to rear heifers prepubertally at the critical prepubertal rate and postpubertally at the highest achievable rates. Insemination should commence immediately after puberty. Furthermore, our results demonstrated that the economic efficiency of a rearing strategy could not alone be evaluated by information on the realized average age at calving.

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