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A 100-Year Review: A century of dairy heifer research[1,2]

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ABSTRACT

The years 1917 to 2017 saw many advances in research related to the dairy heifer, and the *Journal of Dairy Science* currently publishes more than 20 articles per year focused on heifers. In general, nutrition and management changes made in rearing the dairy heifer have been tremendous in the past century. The earliest literature on the growing heifer identified costs of feeding and implications of growth on future productivity as major concepts requiring further study to improve the overall sustainability of the dairy herd. Research into growth rates and standards for body size and stature have been instrumental in developing rearing programs that provide heifers with adequate nutrients to support growth and improve milk production in first lactation. Nutrient requirements, most notably for protein but also for energy, minerals, and vitamins, have been researched extensively. Scientific evaluation of heifer programs also encouraged a dramatic shift toward a lower average age at first calving over the past 30 yr. Calving at 22 to 24 mo best balances the cost of growing heifers with their production and lifetime income potential. Increasingly, farms have become more progressive in adopting management practices based on the physiology and nutrient needs of the heifer while refining key economic strategies to be successful. Research published in the *Journal of Dairy Science* has an integral role in the progress of dairy heifer programs around the world.
Key words: dairy heifer, growth, age at first calving, heifer nutrition

INTRODUCTION

The years 1917 to 2017 saw many great advances in research related to the dairy heifer, and in this time the industry has made many improvements to the way we grow and manage heifers (Appendix Table A1). In the earliest years of the century, the *Journal of Dairy Science* (**JDS**) had very few heifer publications—sometimes <1 or 2 per year related to the growing heifer. However, the later years, notably the past 20 yr, have seen a dramatic increase in heifer research publications, with 20 or more per year. This review includes publications appearing in JDS since its beginning that had the term *dairy heifer* in the title or key words. Papers focusing on preweaned calves and treatments applied to heifers after their first calving were excluded. Topics related to breeding and reproduction, welfare, disease, and housing and facilities are not covered to limit duplication with other articles in this issue of JDS.

In the earliest literature on the growing heifer, researchers identified costs of feeding and implications of growth on future productivity as major concepts requiring further study to improve the overall sustainability of the dairy herd. The status of knowledge of the practical feeding of dairy heifers at the time JDS was established was well summarized by Henry and Morrison (1915; page 426): "The rearing of the heifer after 6 to 8 months of age is an easy task, and perhaps because of this many are stunted for lack of suitable feed." The authors subsequently described the feeding of heifers in approximately half a page, clearly indicating opportunity for conducting and reporting additional research on growth, nutrition, and management.

GROWTH

Growth has been a fundamental outcome of interest in heifer nutrition and management research over the years. Eckles (1920) and Ragsdale (1934) published the first growth standards for dairy heifers at the University of Missouri; standards from USDA Beltsville (Matthews and Fohrman, 1954) and the University of Nebraska (Davis and Hathaway, 1956) followed. Most were derived from a single experiment station herd over

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a period of years, yet all were quite similar in their outcome. In many early heifer studies, researchers characterized growth relative to a "standard" or "normal" heifer using 1 of these reports. There are even instances in which a control group was not included in an experiment because comparisons could be made with such a standard (Maynard and Norris, 1923). Also of interest, in this early period of research many articles contained pictures of the animals on study to supplement growth data with a visual representation of the form of growth. These practices emphasize 2 important concepts of this early work: experiments consistently contained a very small number of animals, and appropriate controls rarely were included.

In one of the earliest reports of growth, McCandlish published measurements from birth to production age and showed that BW consistently increased proportionally to the product of height, depth, and width (McCandlish, 1922). Likewise, height:weight ratio was suggested to maintain a constant proportionality independent of age (Brody and Ragsdale, 1922). Much later, Swanson et al. (1967) published an estimate of optimal growth patterns for dairy heifers. Twenty years after this, Heinrichs and Hargrove (1987) published Holstein heifer weight and height growth standards derived from population studies that showed that heifers were larger than previously published standards, which likely represented changes in breeding programs over time. In addition, they published population growth studies of other dairy breeds from 2 to 24 mo of age (Heinrichs and Hargrove, 1991, 1994). These were (and still are) the most comprehensive publications of growth standards for these breeds.

Summaries of data by Kertz et al. (1998) provided descriptions of Holstein growth through the heifer development phase. Growth rate was fastest in the first 6 mo of life, and feed cost per unit of BW or withers height was lowest during this time. Heinrichs et al. (1992) showed equations predicting BW from other body measurements and published a modified heart girth to BW equation, likely reflecting changes in conformation from early standards (Ragsdale, 1934; USDA/Matthews and Fohrman, 1954). Taking this concept further, Oliveira et al. (2013) developed an equation using heart girth to estimate BW for crossbred Holstein-zebu heifers in Brazil.

Early studies began to relate growth to production and later to economics. Growth from birth to 2 yr was uncorrelated with first-lactation or lifetime-lactation performance (Davis and Willett, 1938). In contrast, Plum et al. (1952) documented a positive relationship between growth of chest girth and butterfat production; however, this relationship was suggested to have been attributable to environmental factors instead of genetics. This same study reported a positive genetic correlation between growth in withers height and butterfat production. Touchberry (1951) and Blackmore et al. (1958) reported a negative genetic association between body size measurements and milk production, with the exception of a positive correlation between withers height and production in the latter study. With the limited data available, it was noted that there was a correlation (44 comparisons, $r = +0.40$) between BW gain during the last 2 mo of pregnancy and subsequent lactation performance regardless of season of calving (Blackmore et al., 1958).

Further studies on growth looked at the genetic relationships of growth and production. Koenen and Groen (1996) estimated the genetic relationship between BW at first calving and other growth patterns and found that estimated mature BW was negatively correlated with rate of maturation, whereas BW at first calving had a strong correlation with mature BW and a negative correlation with maturation rate. Coffey et al. (2006) studied growth of dairy heifers from 2 genetic lines in the United Kingdom: selection for maximum production of fat and protein (select) or average production (control). Under the same management, heifers from the select line grew faster and were heavier at first calving. However, Van de Stroet et al. (2016) showed that larger heifers were not superior in production compared with average-sized animals.

Swanson published a series of papers in the 1960s reporting heifer growth and its relationship to future production (Swanson and Hinton, 1964; Swanson et al., 1967; Swanson, 1971). This helped support his definition that an optimal growth pattern for dairy heifers will develop their full lactation potential at the desired age with minimum expense. Many of these early growth studies used twins to minimize genetic differences, and many of these studies were done with a limited number of animals, often with a variety of breeds. Swanson and Hinton (1964) restricted growth of twin heifers by 25%, and although first-lactation production was 78 to 95% that of the normal-growth heifers, in second and third lactations the pairmates produced almost alike, showing no harmful effect of subnormal growth after the first lactation. However, size of the restricted-growth animals was smaller through maturity. Swanson et al. (1967) studied slowly grown heifers versus those grown at normal rates of gain. Their results showed that prepartum supplementation of the slowly grown heifers allowed them to attain, if not exceed, normal lactation performance. On this basis, liberal prepartum feeding for 9 to 12 wk before expected calving was recommended for heifers if they were substandard in size.

Gardner et al. (1977) published the first work on accelerated growth and early breeding of heifers. They in-